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NORTH ATLANTIC TREATY ORGANIZATION

RESEARCH AND TECHNOLOGY ORGANIZATION

BP 25, 7 RUE ANCELLE, F-92201 NEUILLY-SUR-SEINE CEDEX, FRANCE

***Note:* There is an Addendum to this publication containing the PowerPoint presentations.**

RTO MEETING PROCEEDINGS 72

Strategies to Mitigate Obsolescence in Defense Systems Using Commercial Components

(Stratégies visant à atténuer l'obsolescence des systèmes par l'emploi de composants du commerce)

Copies of papers presented at the Systems Concepts and Integration Panel (SCI) Symposium held in Budapest, Hungary, from 23-25 October 2000.

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14. Abstract

The meeting proceedings from this symposium on “Strategies to Mitigate Obsolescence in Defense Systems Using Commercial Components” was organized and sponsored by the Systems Concepts and Integration (SCI) Panel of the Research and Technology Organization of NATO in Budapest, Hungary from 23 to 25 October 2000.

The symposium's goal was to propose new strategies for obsolescence management including open architecture, functional partitioning and technology insertion that have to be addressed during system engineering, detailed design, production and product support. The symposium outlined actual problems and solutions to the issue of obsolescence by the entire defense system community. It also addressed burning questions related to the problem of parts obsolescence and diminishing manufacturing sources and material shortages. Management tools and methodologies to cope with the risk of obsolescence were discussed. This included new design concepts and system architectures to allow advanced technology insertion during the system life cycle.

Session topics were organized under the four topics of:

- status and experience with COTS technology in defence electronic systems,
- obsolescence management tools,
- new design concepts and architectures to combat obsolescence,
- strategies and initiatives for life cycle management.

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The Research and Technology Organization (RTO) of NATO

RTO is the single focus in NATO for Defence Research and Technology activities. Its mission is to conduct and promote cooperative research and information exchange. The objective is to support the development and effective use of national defence research and technology and to meet the military needs of the Alliance, to maintain a technological lead, and to provide advice to NATO and national decision makers. The RTO performs its mission with the support of an extensive network of national experts. It also ensures effective coordination with other NATO bodies involved in R&T activities.

RTO reports both to the Military Committee of NATO and to the Conference of National Armament Directors. It comprises a Research and Technology Board (RTB) as the highest level of national representation and the Research and Technology Agency (RTA), a dedicated staff with its headquarters in Neuilly, near Paris, France. In order to facilitate contacts with the military users and other NATO activities, a small part of the RTA staff is located in NATO Headquarters in Brussels. The Brussels staff also coordinates RTO's cooperation with nations in Middle and Eastern Europe, to which RTO attaches particular importance especially as working together in the field of research is one of the more promising areas of initial cooperation.

The total spectrum of R&T activities is covered by the following 7 bodies:

- AVT Applied Vehicle Technology Panel
- HFM Human Factors and Medicine Panel
- IST Information Systems Technology Panel
- NMSG NATO Modelling and Simulation Group
- SAS Studies, Analysis and Simulation Panel
- SCI Systems Concepts and Integration Panel
- SET Sensors and Electronics Technology Panel

These bodies are made up of national representatives as well as generally recognised 'world class' scientists. They also provide a communication link to military users and other NATO bodies. RTO's scientific and technological work is carried out by Technical Teams, created for specific activities and with a specific duration. Such Technical Teams can organise workshops, symposia, field trials, lecture series and training courses. An important function of these Technical Teams is to ensure the continuity of the expert networks.

RTO builds upon earlier cooperation in defence research and technology as set-up under the Advisory Group for Aerospace Research and Development (AGARD) and the Defence Research Group (DRG). AGARD and the DRG share common roots in that they were both established at the initiative of Dr Theodore von Kármán, a leading aerospace scientist, who early on recognised the importance of scientific support for the Allied Armed Forces. RTO is capitalising on these common roots in order to provide the Alliance and the NATO nations with a strong scientific and technological basis that will guarantee a solid base for the future.

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Strategies to Mitigate Obsolescence in Defense Systems Using Commercial Components

(RTO MP-072 / SCI-084)

Executive Summary

With the rapid movement towards Commercial Off The Shelf (COTS) solutions within the US DoD procurement agencies and the simultaneous rapid consolidation of the US defense industrial base, obsolescence management and what has been referred to as Diminishing Manufacturing Sources and Material Shortages (DMSMS) is of great concern to both NATO governments and the defense/aerospace industry. Both governments and the defense industry face the dilemma of responding to requests for out-of-production items, primarily from within the semiconductor industry. The discontinuance rate of microelectronics parts has steadily increased. Many recent acquisition reform initiatives have shaken the foundation of the defense electronics industry and the associated government organizational cultures. Solutions to ease the way forward are needed.

The symposium outlined current problems of and solutions to the issue of obsolescence for the entire defense system community. It addressed questions related to the problem of parts obsolescence, diminishing manufacturing sources and material shortages. It also covered the actual status and experience in the application of COTS in defense electronic systems and reviewed associated benefits and drawbacks. Management tools and methodologies to cope with the risk of obsolescence were discussed. This included new design concepts and system architectures to allow advanced technology insertion during the system life cycle, thereby combating obsolescence. Papers were presented during the following sessions:

– Status and Experience with COTS Technology in Defense Electronics Systems
– Obsolescence Management and Tools
– New Design Concepts and Architectures to Combat Obsolescence
– Strategies and Initiatives for Life Cycle Management

Many excellent papers were presented at this symposium providing a good analysis of the problems of and recommendations on how to cope with obsolescence challenges in NATO defense systems. Unless the problem of obsolescence and diminishing manufacturing sources is widely accepted by governments, procurement or organisations and industries, our programs will be severely impacted. It is necessary to build partnerships to reduce diminishing manufacturing sources. We have to confront obsolescence in a proactive manner and plan new technology insertions. Solutions must be orderly, planned and budgeted for. What is needed is total weapon systems life cycle management. Only with this NATO will keep its systems current, operational and available.

Stratégies visant à atténuer l'obsolescence des systèmes par l'emploi de composants du commerce

(RTO MP-072 / SCI-084)

Synthèse

Suite à l'adoption rapide de produits du commerce (COTS) par la direction des approvisionnements du ministère de la défense US, qui s'est produite en même temps que la consolidation rapide de la base industrielle de défense US, la gestion de l'obsolescence, et ce qui a été appelée - Les sources de fabrication en diminution et les pénuries de matériaux (DSMS) - sont devenus un sujet de préoccupation majeur pour les gouvernements des pays membres de l'OTAN, ainsi que pour les industries de la défense/aérospatiales. Les gouvernements et les industries de la défense sont confrontés par le dilemme de savoir comment répondre à des demandes, émanant principalement de l'industrie des semiconducteurs, relatives à des éléments qui ne sont plus fabriqués. Le rythme d'interruption de fabrication dans l'industrie de la microélectronique s'est accéléré de façon continue. La réforme de l'approvisionnement a ébranlé jusque dans leurs fondements et l'industrie de l'électronique de défense et les structures gouvernementales dans ce secteur. Il est, par conséquent, indispensable de trouver des solutions permettant de définir la voie à suivre.

Le symposium a fait le point des problèmes actuels et des solutions envisagées pour résoudre la question de l'obsolescence par les spécialistes des systèmes de défense dans tous les pays membres de l'OTAN. La réunion a examiné des questions relatives aux problèmes de l'obsolescence des pièces, de la diminution des sources de fabrication et des pénuries de matériaux. Elle a évoqué la situation actuelle et l'expérience acquise en matière de mise en oeuvre de COTS dans les systèmes électroniques de défense et a fait allusion aux avantages et inconvénients y associés. Des outils et des méthodologies de gestion permettant de faire face à la menace de l'obsolescence ont été discutés. Les sujets discutés ont compris les nouveaux concepts et architectures de système permettant l'insertion de technologies avancées pendant le cycle de vie du système, pour combattre l'obsolescence. Les communications ont été présentées lors des sessions suivantes :

– Situation actuelle et expérience dans le domaine de la mise en oeuvre des technologies COTS dans les systèmes électroniques de défense
– Gestion de l'obsolescence et outils
– Nouvelles architectures et nouveaux concepts pour combattre l'obsolescence
– Stratégies et initiatives pour la gestion du cycle de vie

Le symposium a présenté des communications d'un très haut niveau, offrant une bonne analyse des problèmes rencontrés, ainsi que des recommandations concernant les moyens de faire face aux défis de l'obsolescence des systèmes de défense de l'OTAN. Si les problèmes de l'obsolescence et les sources de fabrication en diminution ne sont pas pris en compte par les gouvernements, les organisations d'approvisionnement et l'industrie, ils auront un impact considérable sur les programmes de défense. Il est nécessaire de construire des partenariats, afin d'endiguer la diminution des sources de fabrication. Nous devrons faire face à l'obsolescence et prévoir l'insertion des nouvelles technologies. Il s'agit de la prévision méthodique et la budgétisation des solutions. Il faut mettre en place des systèmes de gestion du cycle de vie des systèmes d'armes. Seule cette mesure permettra à l'OTAN de disposer de systèmes de pointe totalement opérationnels.

Click inside the blue boxes or on the titles to view the corresponding section

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† Paper not available at time of printing.
* Papers 31 & 32 were late additions to the programme. They are printed in their correct numerical sequence.

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Theme

Commercial Of The Shelf (COTS) technology in military systems was initiated by the US Federal Acquisition Reform Act as early as 1994. While many military programs still require custom engineering, commercial of the shelf technology is clearly posed to dominate the future of defense electronic systems.

With the rapid movement towards COTS within the US DoD procurement and the simultaneous rapid consolidation of the US defense industrial base, obsolescence management or what is referred to as – Diminishing Manufacturing Sources and Material Shortages (DMSMS) – is of great concern to both NATO Governments and the Defense/Aerospace Industry. Government and defense industry face the dilemma of responding to out-of-production items, primarily from the semiconductor industry. The rate of microelectronics discontinuance has steadily increased. The acquisition reform has shaken the foundation of defense electronics industry and government organizational cultures. Solutions to ease the way forward are mandatory.

New strategies for obsolescence management including open architecture, functional partitioning and technology insertion have to be addressed during system engineering, detailed design, production and product support.

Thème

La mise en œuvre des technologies des composants du commerce (COTS) dans les systèmes militaires a été instaurée par la loi réformant les acquisitions fédérales US dès 1994. Si bon nombre des programmes militaires continuent de prévoir des ensembles fabriqués à la demande, les technologies des composants du commerce semblent être destinées à s'imposer pour la fabrication des futurs systèmes électroniques de défense.

Suite à l'adoption rapide de COTS par la direction des approvisionnements du ministère de la défense US, qui s'est produite en même temps que la consolidation rapide de la base industrielle de défense US, la gestion de l'obsolescence, communément appelée – réduction des sources de fabrication et pénuries de matériaux (DSMS) – est devenue un sujet de préoccupation majeur pour les gouvernements des pays membres de l'OTAN, ainsi que pour les industries de la défense et aérospatiales. Les gouvernements et les industries de la défense sont confrontés au dilemme de savoir comment répondre à des demandes, émanant principalement de l'industrie des semiconducteurs, relatives à des éléments qui ne sont plus fabriqués. Le rythme d'interruption de fabrication dans l'industrie de la microélectronique s'est accéléré. La réforme de l'approvisionnement a ébranlé jusque dans leurs fondements et l'industrie de l'électronique de défense et les structures gouvernementales dans ce secteur. Il est, par conséquent, indispensable de trouver des solutions permettant de définir la voie à suivre.

De nouvelles stratégies de gestion de l'obsolescence, y compris l'architecture ouverte, le découpage fonctionnel et l'insertion des technologies, doivent être examinées lors des phases de l'ingénierie des systèmes, du projet détaillé, de la production et du support technique.

Systems Concepts and Integration Panel

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Technical Evaluation Report

by

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INTRODUCTION

Background

Since 1997 the Research and Technology Organisation (RTO) has been NATO's single focus for defence research and information interchange. The System and Concepts Integration (SCI) panel is one of six panels that cover the scientific and technical disciplines that bear upon defence issues. The SCI panel deals with advanced system concepts, integration, engineering techniques and technologies applicable to all platforms and operating environments, concentrating on mid to long term system level operational needs.

During the period of operation of the RTO and the SCI panel, very significant changes have taken place in the area of defence procurement. The ever increasing cost of acquiring military hardware and software, together with major shifts in the electronics marketplace, prompted Defense Acquisition Reform in the USA as an attempt to leverage the defense dollar through utilization of commercial technology advances.

The decision, prompted by the now famous "Perry Memorandum" of 1994, to move towards performance based specifications led to the virtual abandonment of the MIL-STD and MIL-SPEC system that had underpinned military procurement for several decades. At the same time the market in semiconductors was increasingly being driven towards commercial telecommunications and computing needs, resulting in a reducing number of types and sources of military components. This effect has also been felt, although to a lesser extent, in the material supply and non-semiconductor component markets. In combination these effects produce an ongoing obsolescence problem for legacy, or fielded, defence systems worldwide.

The impact of Diminishing Manufacturing Sources and Material Shortages (DMSMS) can vary from the merely irritating to the showstopper. It is of grave concern to the NATO governments and the Defence and Aerospace industry, and the rate of discontinuance of part availability is steadily increasing. Many programs such as the F22 stealth fighter, AWACS, Tornado and Eurofighter are suffering from obsolescence. Concurrently with this increasing rate of military part obsolescence has come a progressive acceptance of the use of Commercial Off The Shelf (COTS) components, assemblies and systems in the defence arena. It is against this background that the SCI panel initiated this symposium.

Theme

The reform of the acquisition process in the Defence Industry has radically altered the culture of the Defence Electronics Industry and Governmental Organisations. The steadily increasing rate of microelectronics discontinuance demands improved obsolescence management be employed. The migration to the use of COTS in defence systems has been viewed as a possible solution to current obsolescence. This symposium was convened to review the actual problems and solutions to the issue of obsolescence as experienced by the entire defence community. It sought to examine new strategies for the management of obsolescence such as the use of open architectures, adopting a systems engineering approach, and employing planned technology refresh/technology insertion throughout the equipment or system life cycle, from initial design to product support.

Purpose and Scope of the Symposium

The purpose of the symposium was to address the burning questions related to the problems of parts obsolescence and diminishing manufacturing sources and material shortages, to review the management tools and techniques employed in dealing with obsolescence, and to examine the current status and experience in the application of COTS in defence electronics systems. The meeting would also examine new design concepts and system architectures that allow the insertion of advanced technology during the system lifecycle and thus mitigating obsolescence.

The declared scope of the Symposium is best summarised in the four sessions by which the meeting was organised.

Session I – Status and Experience with COTS Technology in Defense Electronic Systems.
To present current defence industry experience in the application of COTS technologies and components to

defence electronics systems, highlighting the successes and difficulties encountered and the lessons learnt.

Session II – Obsolescence Management and Tools.
To discuss the variety of methodologies and tools available today and proposed for the future, which facilitate the proactive management of obsolescence.

Session III - New Design Concepts and Architectures to combat obsolescence.
To address the system engineering approach to obsolescence mitigation through the use of design concepts and architectures that are effectively technology transparent and as such are significantly immune from the effects of component obsolescence.

Session IV –
To address the strategic viewpoint in approaches to obsolescence management, seeking to adopt an holistic, long-term perspective.

EVALUATION

General

The subject matter of the symposium is such a widespread and debilitating phenomenon that the need for the RTO to organise such an event is indisputable.

Every defence force in NATO is suffering an increasing rate of attack on their ability to field current, legacy systems due to part obsolescence. The same issue is also hampering procurement of follow-on and new systems and equipment.

Somewhat perversely, the rapidity of part unavailability is less for legacy systems designed in the 1970's and 1980's than in their replacements currently being deployed or under development. Modern fighter aircraft such as Eurofighter Typhoon, find themselves at the front edge of the curve through use of advanced microelectronic devices, which are themselves out of production before the aircraft has made its first production deliveries.

The spectrum of obsolescence effects is broad. It encompasses not only advanced microelectronics, but also materials used in legacy systems for which there is no longer a MIL-Spec. nor a supplier; basic electrical piece parts for which the market has dwindled to the re-supply of military hardware; software which is no longer compatible, and is neither supported nor modifiable to meet today's requirements. It is due to the incredible growth in commercial microelectronics over the past twenty years, and the consequent abandonment of the military market by most of the major integrated circuit manufacturers during the same period, that the debate on obsolescence in defence systems tends to focus on the effects of microelectronics obsolescence on equipment and systems, almost to the exclusion of all else. Modern weapons platforms comprise a number of systems; those systems are made up of several equipments, and it is at the equipment level that obsolescence has its most immediate impact. It is not unnatural therefore that the Symposium has tended to focus on the trials and tribulations of equipment suppliers seeking solutions that are often not within their gift to implement, but instead lie with the prime contractor and the government procuring agency.

Given that, the Symposium was still slightly unbalanced, in that there were precious few papers citing actual experience of using COTS. Overall insufficient distinction was made between the separate problems of maintaining legacy systems, and minimising the effects of obsolescence in new build systems. If obsolescence is not designed out, then it is designed in.

Only one paper (paper 1) addressed itself directly to the fundamental question posed by the title of the symposium, i.e. is the use of commercial components in defence equipment a good strategy for mitigation of obsolescence. All of the other papers were concerned with individual approaches to specific problem areas and not to the success or otherwise of the strategy overall. This may be a further reflection of the opinion, stated earlier, that the effects, and consequently the problem solving efforts, are concentrated in the equipment supply echelon of the defence procurement hierarchy. Strategy formulation tends to be the preserve, and concern, of the weapons platform system authority and their customers, the national defence procurement agencies, who have tended to flow down rigid requirements specifications that leave little room for manoeuver.

This technical evaluation of the Symposium deals with the papers as presented in the context of their sessions, and discusses the arguments presented therein. The overall outcome of the symposium is set in a broader context in the conclusions.

Keynote Address

Mr. Ted Glum, Director of the Defense Microelectronics Activity (DMEA) located at McLellan AFB in California, gave the keynote address. Refreshingly, Mr. Glum's presentation was directly relevant to the subject matter of the Symposium and indeed offered one solution to the problems of obsolescent parts, especially in the case of legacy or fielded systems.

His opening remarks painted the landscape that forms the backdrop against which all our current efforts to deal with obsolescence are set.

- Increased reliance on microelectronics in our systems, the supply of which is increasingly unstable.
- Incompatibility of weapon system lifecycles of 20/30 years, with the current 18 months mean time between IC technology iterations.
- The entire Defense industry share of the global microelectronics market is now only about 0.3%, so our influence on the component manufacturers is minimal.
- Obsolescence is a business decision, made by these component manufacturers.

He also alluded to the familiar problem arising from project organisation structures, which faced with the common problem of obsolescence, devise individual solutions for their project area, leading to unnecessarily high operation and support costs. It was to combat this that the US DOD invested in the creation of DMEA and gave them the mission to provide microelectronics technology solutions. Reactive strategies used heretofore represent the antithesis of modern business philosophy and tend to produce technical solutions not business solutions.

DMEA promotes proactive strategy, recognising that obsolescence is a business decision and that technical solutions must have a valid business case, and by providing common solutions to common problems across the boundaries of projects, DMEA's engineering capabilities enable a range of tailored solutions to be offered.

The US government's investment in 'Flexible Foundry Technology', together with government held process licences and agreements on terminal transfer, enables DMEA to provide prototype/low volume manufacture and supply of obsolete or specialist parts, including 5 volt devices. The effectiveness of this approach/setup has already been demonstrated in providing solutions to F-22, F-16 and B-2 obsolescence issues. The DOD are effectively proposing a series of initiatives through DMEA, including industry partnership, the unique flexible foundry and leveraged technical solutions with business models, as their answer to the challenge of minimal market leverage and increased reliance on critical technologies.

Session I – Status and experience with COTS technology in Defense Electronic Systems.

The late withdrawal of paper 3, together with the earlier loss of paper 4, left only four papers to be presented in this opening session.

The presentations covered many different aspects of the use of COTS in Defence Systems, from detailed environmental considerations of fast jet use to ground systems implementations using COTS systems and software. The titular theme of the symposium was addressed in paper 1, which reviewed the key difficulties for an Avionics supplier confronting the problems of obsolescence and considering the use of COTS components. There is an incompatibility between the lifecycles of weapons platforms and microelectronic components, and this was pointed out. Also, Diminishing Manufacturing Sources (DMS) result in an inability to procure military components for long term product support. Therefore the use of COTS parts in military systems has become a necessity. However, it was argued that the use of COTS to mitigate obsolescence is a contradiction in itself. COTS are more part of the problem than part of the solution, and provide an additional challenge to proactive obsolescence management, which is an essential part of tomorrow's programmes planning. A major obstacle to the use of COTS today is the continuation of rigid requirements still being flowed down to equipment suppliers in RFQ's. The theme of incompatible product vs. part lifecycles was refrained in the second paper (paper 2), which also introduced further key themes of the symposium – open architecture, modularity, and planned technology insertion strategies. The speaker suggests we consider COTS procurement as a process that must be adopted to achieve the true benefits of COTS. Obsolescence Management is part of a lifecycle management approach that must be tailored to suit the needs of the individual product and programme. The design may be frozen at entry to production phase, with Lifetime buys to cover foreseeable product maintenance and support needs, or else involve a combination of modular open architecture design, with planned technology insertion. For this approach to be effective it requires a supply chain partnership to mitigate the effects of Obsolescence, the causes of which are outwith our direct control.

One of the major impediments to the wider use of COTS devices in military avionics is the incompatibility of environmental requirements specified for the parts and for the equipment. Two solutions exist – 'uprate' the individual components to meet the operational environment, or 'derate' the operational environment to suit the components. The third paper (paper 5) in this session addressed this latter approach, specifically addressing the methods that can be used to improve the environmental control system on a fast jet fighter. These include a new approach to Environmental Control System (ECS) design - existing ECS designs are based upon fifty year old concepts, improved EMC design and active damping to reduce the effects of vibration. In adopting this top-down approach, the prime contractor provides one common solution for all his avionics suppliers, thus preventing the proliferation of individual, unique solutions that will be more expensive overall, and less supportable at system level. This perspective echoes one of the themes of DMEA in the keynote address. Overall the life cycle cost of using ruggedised, specialist designed avionics will probably exceed the cost of adapting the aircraft environment to suit non-ruggedised COTS equipment. However, such changes to the airframe environment must always bear in mind

the performance, power, weight and offensive load carrying characteristics required to complete the aircraft mission.

The final paper of the session (paper 6) demonstrated that, when constrained by very tight financial and timescale limits, innovative COTS based solutions could be provided to update an obsolete system. The Hungarian Air Defence System was updated to include an Air Sovereignty Operations Centre (ASOC) with digital data links to the civil and military radar's operating in the country. This was achieved using 80% commercial components, systems & software. In two years of operation the system reliability is limited by the reliability of the legacy radar equipment. Use of COTS may therefore be a valid strategy for providing a swift and low cost upgrade to obsolete ground sector equipment in the short to medium term.

Session II – Obsolescence Management and Tools.

Eight papers were presented in this session, including a late addition. The new themes in this session were the adoption of a system engineering approach, the benefits from the use of information technology to provide timely notification of obsolescence and to manage it, and the use of software tools to create virtual hardware definitions which are therefore technology transparent.

The first paper (paper 7) provided a comprehensive description of a system engineering assessment model for use as a tool to cope with the risks associated with the use of COTS in the system life cycle. This methodology was developed for use in the US naval air systems command to assess the most cost effective COTS equipment based on affordability, reliability, mission requirements and ability to accommodate future modification and update. Beginning with the mission need, a requirements analysis, equipment classification and market research are carried out, followed by an alternatives risk assessment and risk mitigation, including validation. The conclusion of the process is an input to procurement. This risk-based systems engineering assessment model provides a common framework for making COTS technology decisions by assessing the relative risk of each COTS alternative. It also provides assistance in determining the appropriate degree of validation required to verify that a COTS alternative can be transferred to the military environment.

The second paper (paper 8) dealt with the more specific problem of preserving the longevity of Asics's and associated devices such as PLD's and FPGA's. The approach adopted was to form an industrial consortium called COCISPER to pool experience and methods, and to develop an operational guide that outlines the methodologies to be employed in the design and manufacture of Asics's. The guide has been made available to a wider audience via the Internet, and in scope covers the entire process from technical requirements specification to project and risk management and durability assurance. This on the whole represents an obsolescence strategy that is a combination of life time buy, grouping together to create a sizeable market, source control, and technology transparency through the use of VHDL system definition & description.

The cost impact of software changes consequent upon a hardware change is recognised in the next paper (paper 9). Development of major equipment such as radar can be very costly in time and money. The approach proposed here was to make extensive use of simulation to design a virtual prototype, which is hardware independent, or technology transparent. The library of algorithms, models and workshops is made available not only for initial development, but also for upgrades, thus providing a further 'hedge' against subsequent obsolescence effects.

The use of commercial database tools and information exchange service to mitigate obsolescence was promoted by 'i2', who now own TacTech (paper 31). The tool provides a notification process, replacement options and component usage assessment for single or multiple projects. The availability libraries are updated daily and form the backbone of this information system, which is primarily an aid to legacy system obsolescence management, and is used as an obsolescence notification service by many Defence equipment suppliers in NATO countries.

A beneficial approach to using COTS software and simulation tools in Defence Systems was presented by Virtual Prototypes Inc., in the form of their Enterprise Software Framework. (paper 11) VPI claim that their software will mitigate obsolescence effects through reduction in technical and schedule risk by machine generation of code and re-use of knowledge and information.

The need for different strategies to be applied to different product types; i.e. existing 'legacy' products and new development products, was recognised in the next presentation (paper 12). Legacy products are, by and large, dealt with by a passive strategy, corrective action being applied on a reactive basis. New programmes, however, take proactive obsolescence management as a key design requirement. Advanced design criteria and the use of open architecture concepts with COTS device families is the basis of this new approach. Hardware and software functional standardisation is driven deeply into the open architecture design; modularity at sub-module level increases hardware robustness. Selection of COTS devices is a defined process with key components selected to have a good commercial availability in 'Industrial Quality Level', have multiple suppliers and be compatible with the most popular backplane buses and standard interfaces. The open system architecture is modular and scalable, and arranged in layers with clearly identified logical and physical interfaces, and with global and local bus networks selected for longevity as well as performance. System design has recognised that software package development and

certification significantly outstrips the equivalent hardware process in most cases, and used standard COTS OFP software factories and COTS operating systems to minimise the impact of software obsolescence. The building blocks of this proactive approach are: the open architecture and modular design, which permit changes and updates with a reasonable level of risk and cost; a product configuration, which is maintained for a specific period by last time buys per batch and minor changes; and finally, by a planned periodic product enhancement permitting obsolescence removal activities with relevant design enhancements.

Paper 32, which followed, was a somewhat esoteric treatise on methods for making classified documents more secure from copying using a variety of techniques. The paper was a late addition provided by the Hungarian hosts, and was relevant to this section in that it involved software tools & techniques, although it did not directly reference obsolescence.

The final paper (paper 14) in the session reviewed the tools and methods employed by Thomson CSF Group to combat obsolescence. These tools operate on four levels that equate to a flexible response strategy, tailored to project and customer needs. Customers in different markets react differently to the problems of obsolescence, but it is ultimately the equipment manufacturer who must resolve the problem, and thus must equip themselves with the means to do so. To ensure consistency of approach across a disparate group, TCSF set up a common obsolescence control system, with common tools and methods, which are applied at the appropriate stage of an equipment's life cycle and level of maturity. The tool-set encompasses reactive and proactive elements, including an obsolescence warning system, an end of life predictor tool, a knowledge-based technology evolution predictor tool, parts list analysis and review processes, and all overseen by an obsolescence task team whose role is to help business units formulate solutions. Since 'upstream' obsolescence risk mitigation is rooted in technical choices, TCSF has evolved an incremental design procedure, which allows for technology refresh/insertion throughout the product lifecycle. Overall, this approach is exemplary and must be commended. That such a complex organisation has so clearly identified the issues of obsolescence management and empowered a structure to deal with it so comprehensively reflect well on their management.

Session III – New Design Concepts and Architectures to Combat Obsolescence.

The third session contained eleven papers, in which the major themes examined were modular and open architectures, associated software techniques, and system design for flexibility and obsolescence mitigation. The opening two papers were concerned with aspects of the Allied Standardised Avionics Architecture Council (ASAAC) project, whose prime objective is to define a flexible avionics architecture that will balance affordability constraints with combat capability and combat availability. Principally ASAAC is aimed at reducing life cycle cost and improving operational performance. The architecture described in paper 16 is open, the logical structure is layered, and is the basis for integrated modular avionics populated by common functional modules, with defined physical and logical interfaces.

An example of this approach was given in paper 15, where a Mission Management System (MMS) is being developed using the ASAAC structures. This MMS makes extensive use of COTS hardware and software technology, has functional modularity and open architecture for technology transparency.

An alternative solution presented in paper 17, is that of system on chip. These devices contain CPU cores and DSP functions, with defined standard interfaces. The design flow is based on that outlined by the COCISPER consortium in paper 8 above. The device is created as a virtual component defined in VHDL, and as such is technology transparent; and the use of virtual prototyping speeds development and upgrades, thus reducing life cycle costs.

Paper 18, described the development of an open computer system for military avionics, using COTS computer components. This universal aircraft computer (UAC) is constructed from well-established commercially available hardware and software and has a layered open architecture, enabling software to be ported to different hardware configurations with minimum effort.

The embodiment of COTS components and modules in a modern avionics architecture was described in the next presentation (paper 19). In upgrading the avionics suite, extensive use was made of COTS general aviation equipment and COTS Processors and Displays. The result is a state of the art system, which is cost effective with reduced development risk and improved supportability.

The next paper (paper 20) described the use of a distributed architecture as the basis for a computing system that is fault tolerant, uses COTS systems and re-uses obsolete CPUs.

Strategies developed by EADS for dealing with obsolescence were outlined in paper 21. They recognize that 80% of overall product costs are committed in the first 20% of the development cycle, therefore the problem of DMS needs to be addressed at the earliest stage – when the architecture is being defined. A modular hardware approach, using functional building blocks, together with a layered software model reminiscent of the ASAAC approach, and standard interfaces, produces a flexible design that can accommodate frequent updates. Additionally, they are investigating the creation of a moderate thermal and mechanical environment to accommodate the increasing use of commercial components.

That we should take an holistic view of obsolescence was argued by the next speaker (paper 22). Electronic component unavailability is just a 'special case' of the general form of obsolescence that arises when a system no longer provides and adequate solution to a user's problem. Obsolescence Management needs to plan for continuous change. A system engineering approach is a structured way of taking the holistic view, and obsolescence is now a key element in the system engineering methodology.

The ever-increasing cost of software obsolescence and techniques for reducing it were illustrated with reference to the development of a demonstrator Radar Data Processor (paper 23). The key elements in this process were the creation of integrated Systems and Software teams; the use of state of the art software tools; and the implementation of the Rapid Object-oriented Process for Embedded Systems (ROPES) methodology. Mitigation of obsolescence comes from the ability to re-use sub-systems.

Paper 24 continued the theme of using software flexibility to insulate hardware from the ravages of obsolescence. The example given was a software radio for multi-band, multi-mode and multi-role operation. Again the utilisation of a modular architecture, and a sharp division between hardware and software, permits low risk module replacement to overcome obsolescence impacts.

The final paper in this session (paper 25) considered test equipment, which is often the last equipment to be considered, but can suffer obsolescence effects as readily as the front line product. Test system architectures must achieve long term maintainability, whilst being regularly updated to keep abreast of the equipment under test. EADS adopted a 'philosophy of standardised units' and defined the test set critical interfaces, allowing them to develop a modular system that can evolve through hardware and software module replacement. The system makes maximum use of COTS equipment, software and protocols.

Session IV – Strategies and Initiatives for Lifecycle Management.

The five papers in this session examined the use of COTS and COTS-based systems from a life cycle management perspective. The first paper (paper 26) very coherently summarised the management challenges thrown down by COTS-based IT systems in Defence acquisition.

Whilst COTS offer the promise of being 'faster, better, cheaper', they also come with more rapid obsolescence, lack of control, lack of underlying design detail, out of step with military requirements etc., and management cognition of these difficulties is essential. COTS-based systems are inherently complex and require adequate resource to be applied throughout the life cycle, since a COTS-based system is effectively in a state of continuous design improvement. This means that the total lifetime costs of such a system is impossible to accurately predict at this time, and this conflicts with current Defence acquisition strategies. The complexity, and potential variety, of COTS-based systems demands a paradigm shift in the management approach of all stakeholders, from suppliers to end- users.

The theme of the management challenge of COTS was continued in the second paper (paper 27) of the session. Recognition that COTS means constant change, must lead to planning for change and for operating with multiple configurations and open systems. Procurer and supplier must work together in a win-win stakeholder relationship to ensure cost-effective and timely decision-making.

The paradigm shift needed between traditional and COTS-based acquisition is highlighted in the third presentation (paper 28), which uses the example of Software COTS items. Control and visibility are key issues, which become problematical with COTS software, and its open commercial nature necessarily means that it is available to potential enemies. The use of open source software such as Linux Operating System (OS) offers the control and visibility of bespoke software, without the cost, and promises vital advantages in dealing with obsolescence in that appropriate changes can be made to the OS such that the application suite need not be altered. The flexibility and modularity of Linux make it complex to specify for procurement. A Linux Centre is proposed to act as a focus for the needs of the Defence community who want to use Linux, whilst maintaining links to the global Linux community.

The penultimate paper (paper 29) discussed a new approach – an integrated Reduced Total Cost of Ownership, which sets out to show that new technology can reduce the life cycle cost of an aircraft by over 40%, despite conservatism in the cost estimating community. Extensive use of Design for Manufacture and Assembly computer aided engineering and re-engineering, enabled significant reductions in parts count and assembly cycle times to be realised and improvements in reliability and maintainability achieved. The study concluded that the integration of new technology, flexible acquisition systems and advanced processes can reduce cost of ownership of aerospace systems.

The final paper (paper 30) of the Symposium very effectively summed up the current reality of obsolescence management, which is generally reactive, and that individuals solving individual problems was wasteful of scarce resources. The speaker described a National Obsolescence Centre, which would address obsolescence on a Global basis. The Centre would combine the resources of DERA and industry and provide a single focus for obsolescence information and an affordable obsolescence management service to small and medium sized companies, who would otherwise struggle to afford effective solutions to their obsolescence problems. It could also act as a focal

point for promotion of new approaches such as Physics of Failure, Health Unit Monitoring, and maintenance/failure free operating periods as part of a built for life electronics project. The combination of maintenance /failure free operating periods with open systems architectures could offer a low cost solution to the obsolescence problem as well as providing planned seamless technology upgrades and known equipment reliability.

Conclusions.

The Symposium was attended by 128 individuals, from 21 countries, and the overwhelming view expressed by the attendees who returned questionnaires, was that the event had been very good to excellent. Most people considered that it had been very worthwhile, and that the theme of the symposium was very appealing and topical. The papers presented were judged, in the main, to have met the objective of the symposium and were of a satisfactory level and mostly relevant to the theme of the conference. There was a similar level of satisfaction expressed with regard to the organisation of the speakers and their use of visual aids, and the time allowed for their presentations and for discussion and exchange of ideas.
Two papers, paper 14 on the comprehensive tools and techniques employed by Thomson-CSF in their efforts to combat obsolescence and paper 26 on management issues involved with the use of COTS based IT systems, were adjudged the most interesting. However, the votes were very widespread, with the papers in session II accruing most votes, which may be a reflection of the composition of the audience which contained a high proportion of Defence Industry Contractors, who were interested in the practicalities of obsolescence management today. It is unfortunate that there were so few attendees from the Customer and Procurement communities, since the lessons learnt and the problems still encountered would have been enlightening for those who effectively set the boundaries within which the majority of speakers and attendees must function.
In general the organisation of the Symposium, the location and the hospitality of the Hungarian hosts was universally approved. One minor drawback was that the translators, who were excellent, could be heard a little too loudly in the auditorium due to a lack of adequate sound proofing of the booths, which was distracting to those at the rear of the hall.

The major technical themes dealt with in the symposium were:

- Obsolescence management of current or legacy electronic equipment & systems.
- Mitigation of the effects of obsolescence in new designs.
- Discussion of the pros and cons of using COTS components in military systems, and their effect on obsolescence management.

The symposium title perhaps implied a wider debate than that which it exited, as many presentations focused on the problems of microcircuit obsolescence in electronic equipment. As noted earlier, this is understandable, given that the sharpest pain of obsolescence is currently felt by equipment manufacturers through unavailability of advanced microcircuits. The problems and solutions encountered in this area should be regarded as a special case of the general problem of obsolescence, as pointed out in paper 22, and they have ‘read across’ to a wider spectrum of obsolescence issues.
The keynote speaker, in his excellent presentation, described the large investment made by the DOD to ensure a supply of microcircuits for their legacy systems, thus effectively warding off the effects of obsolescence by controlling parts supply. Most Defence contractors rely on a reactive strategy for their legacy systems, e.g. papers 12 & 14, and to be effective this depends upon good quality obsolescence information, which can be supplied internally (paper 14), or externally by a commercial venture or government sponsored centre (papers 31 & 30). There is no one solution to all difficulties resulting from component unavailability, several of the presentations made this clear. Tailoring of the obsolescence solution to the customer and product and type of obsolescence is required, and involvement of all stakeholders is also necessary.
Future systems demand an holistic, systems engineering approach, to the threat of obsolescence. Unless the system is, from the outset ,designed so far as is possible to minimise or eliminate obsolescence effects, then it will inevitably succumb. System designs should be modular in both hardware and software, and should employ an industry standard open system architecture, with extensive use of software tools to define and simulate system modules thus making the system design technology independent. A number of papers gave examples of the work currently being done in this area, papers 15,16,18 &21 all reference the ASSAC architecture which looks very much like a basis for future products. This architecture has a ‘layered’ software structure, and this is essential if the costs of software upgrades, initiated by hardware obsolescence, are not to spiral out of control. The whole vexed question of software obsolescence was in general presented within the context of hardware initiated changes. Techniques for lessening obsolescence effects on software were described in paper 23, and such techniques will be crucially important to future project cost containment. In proportion to the potential costs, insufficient debate on software obsolescence was presented at this event.

The proactive system engineering design approach is also an essential part of the use of COTS components in military systems. COTS *can* be used as a solution for obsolescence, but *only short term,* since they are subject to even shorter lifetimes than the now vanishing military parts as outlined in paper 1. COTS require a more protected environment and open architecture modular systems with planned upgrades to refresh the technology and insert new technology. Work is ongoing to improve the avionics environment in future aircraft, which will benefit the COTS based equipment (paper 5). However, management issues regarding the use of COTS and COTS-based systems need a rethink of the procurement process. A paradigm shift is required; the traditional adversarial procurement approach is too inflexible to deal with the variety and complexity of COTS equipment. The partnership approach between Government and industry should be promoted, with obsolescence identified as a risk to be jointly managed. The issue of support of fielded COTS-based equipment raises the question of the level, and location, of repair, and demands smart solutions.

It is obvious, from the presentations and attendees, that the effects of obsolescence are so universal, we must work collectively to establish common solutions, rather than devise individual solutions to common problems. Working through organisations such as the National Obsolescence Centre, or the Component Obsolescence Group (COG) in the UK, DMEA in the US, and so forth, is the way forward for the many small to medium sized companies in the Defence business.

Overall, the author feels that the Symposium satisfied its objectives, and provided a beneficial exchange of ideas and information.

Recommendations

This Symposium was timely, as the unavailability of state of the art military parts means that COTS are virtually ‘the only game in town’, and unless cognizance is taken of the issues associated with their use in military systems costs will spiral beyond control. Further, as the cycle of change for hardware shortens, the costs and effort associated with software upgrades dominates the project. Thirdly, planned technology insertion strategies will incur the overhead of re-qualification/re-certification, and area not much discussed at this event.

For future work, I would recommend:

- A Workshop on the management issues associated with the procurement and use of COTS components and COTS-based systems, and targeted at the customer and procurement communities. This should include consideration of the effects of widespread use of COTS on the Logistic Support community.
- A Workshop or Symposium on Software Obsolescence.
- A Workshop dealing with the problems of re-qualification/re-certification of military equipment which is subject to planned technology insertions.
- A workshop addressing cost forecasting for COTS-based systems.

Click here to view PowerPoint presentation; Press Esc to exit

United States Department of Defense Initiatives for the Management and Mitigation of Microelectronics Obsolescence

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The United States Department of Defense (US DoD) and its allies increasing rely on “smart” weapon systems to provide both a strategic and tactical edge on the battlefield. The components that make these systems smart are the complex microelectronics devices that form the core of their functional capability. However, this same semiconductor technology upon which we rely turns over every 18 months or less and is normally supported for no more than six to seven years. Yet the US DoD and its allies keep their weapon systems in operation for ever-increasing periods of time, and often requiring the availability of “unique” microelectronics devices for 20 or more years. Therefore, the problem facing the DoD and its allies is not the ability to acquire advanced technology during weapon system development, but rather the inability to acquire this technology during the out-years in order to keep hi-tech weapon systems supported. This emphasizes the need for the development of management techniques and solution based strategies to handle the problem of microelectronics obsolescence.

Commercial Use Of Technology Drives the Market

In today’s global economy, the US DoD represents less than 3% of the world semiconductor market. In this environment, a Defense customer, supporting a fielded weapon system, usually has a requirement for several hundred or perhaps several thousand of a particular microelectronic device. However, these customers must compete against large high-volume commercial interests (i.e., cellular telephones, personal computers, network switching systems, etc.). These commercial requirements demand access to the newest technologies, with parts orders in the millions of devices. Semiconductor manufacturers, who make decisions based upon profitability, tend to move with the market place. In the case of military versus commercial applications, the trend shows manufacturers closing their low volume, less profitable military product lines and concentrating on their highly profitable, high volume commercial product lines. The problem only worsens as we look at the big picture.

The Problem is Compounded

It is a fact that Microelectronics obsolescence is a horizontal, technology-based issue rather than a vertical one, since systems throughout the entire US DoD use the same or similar microelectronics devices. Simply put, when a device becomes obsolete, every weapon system using that device has a problem. With reduced Operations and Support funds available, wholesale replacement of fielded systems is increasingly unaffordable. Complicating the picture even further is the need of the US DoD and its allies for 5 Volt logic device technologies, which have been designed into our weapon systems over many years. But at the same time, industry is rapidly abandoning 5 Volt logic in favor of 3.3 Volt and lower voltage circuits.

As it is true of the problem, the solution must have the ability to cut across the many weapon systems throughout the entire DoD. Therefore, the DoD established an organization to combat this area of critical concern.

The US Defense Microelectronics Activity – The Key to US DoD Initiatives

On 23 July 1996, the Deputy Secretary of Defense, The Honorable Mr. John White, issued a memorandum establishing the Defense Microelectronics Activity (DMEA). The DMEA was established by the Department of Defense to provide a broad spectrum of microelectronics services to US DoD. The DMEA, located in Sacramento California – close to Silicon Valley, is under the authority, direction and control of the Deputy Under Secretary of Defense for Logistics, Readiness & Material Management.

Its primary mission is to leverage the capabilities and payoffs of advanced microelectronics technology to solve US DoD operational problems in existing weapon systems, increase operational capabilities, reduce operation and support costs, and reduce the effects of Diminishing Manufacturing Sources (DMS)/obsolescence for microelectronics components. In this capacity, the DMEA assists weapon systems managers, and managers of other operational or developmental systems, in

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inserting advanced microelectronics technologies, ensuring lifetime sustainment of these systems which are dependent on microelectronics, and provide studies and analysis relative to existing or future obsolescence problems. It addition to supporting US Defense organizations, the DMEA acts as a resource to other federal agencies, state governments, U.S. industry and foreign entities.

Another established role is as the US DoD's Executive Agent for Integrated Circuit (IC) Microelectronics DMSMS. As such, DMEA is a key player in the development and coordination of solutions to US DoD's obsolescence problems and is responsible for issues relating to IC microelectronics obsolescence. In this role, DMEA has developed several key initiatives for the US DoD to curb the effects of microelectronics obsolescence.

DoD-DMEA Initiatives

Acquisition Guidelines – A comprehensive guidebook developed to provide the tools and techniques necessary to assist government decision makers, weapon system program managers, integrated product teams, and support personnel during all phases of the weapon system acquisition process. The goal is to reduce the costs associated with microelectronics obsolescence by using "smart procurement" strategies.

Advanced Technology Support Program – Provides rapid access to in-house DMEA engineering capability, including its microelectronics engineers and "world class" laboratory facilities containing $200M USD of engineering analysis, design, test and limited production equipment. This unique enterprise also provides access to the United State's top defense contractors through the program's $875M USD in contracts. This strategy offers defense agencies a comprehensive mix of solutions through a unique and synergistic combination of government and industry expertise. Program activities range in complexity from discrete electronics through integrated circuits, circuit boards, modules, assemblies, subsystems, and systems. Typical solutions include developing form, fit and/or function (FFF) replacements and advanced technology insertions and applications.

Best Management Practices – DMEA developed in cooperation with US Military services and Industry Groups a step-by-step strategy document for managing microelectronics obsolescence. It provides practical techniques and approaches to aide weapon system support personnel in establishing a multi-level - comprehensive microelectronics obsolescence management program. It is applicable for use at all stages of the weapon system life cycle.

DMEA Flexible Foundry – "The Ultimate Insurance Policy"

The DMEA Flexible Foundry was established to solve the problem of long-term microelectronics availability for military weapon systems. This unique capability provides the means to fabricate a vast array of obsolete microelectronic devices as well as cutting edge technologies. This one-of-a-kind facility is located at DMEA in Sacramento, California - USA.

Through the flexible foundry, DMEA has solved the problem of microelectronics availability from now closed or discontinued process lines. This is accomplished through successful partnerships with the semiconductor industry by licensing and fabricating proven industry microelectronics processes. These processes run simultaneously or in tandem in the DMEA foundry—thus, it is a Flexible Foundry.

This technical and business model assures a continued US DoD supply of microcircuits as industry flexes with the market—low volume, on-demand requirements can be met. Logic circuits, amplifiers, regulators, mixed signal ASICs, gate arrays and radiation-hardened devices are but a few of the types of microcircuits supported by the Flexible Foundry.

Conclusion

The US DoD and its allies face the daunting challenge of managing and solving the problems caused by microelectronics obsolescence. World economic market forces are quickly eroding the clout of the once powerful military industrial complex, as once steady supplies of military product lines are pushed aside for more profitable-high volume commercial product oriented microelectronic devices. To rise to this challenge, the US Department of Defense established the Defense Microelectronics Activity, an organization with the mission to address the full spectrum of microelectronics issues. Through innovative strategies, the DMEA has developed a series of initiatives to help the US DoD and its allies manage and solve their problems of microelectronics obsolescence. DMEA's "Flexible Foundry", meets long-term defense requirements by providing a future source for critical microelectronics technologies for our "smart" weapon systems.

The Use of Commercial Components in Defense Equipment to Mitigate Obsolescence. A Contradiction in Itself ?

by

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(October 2000)

Abstract:

The paper identifies and discusses the presently unresolved contradictions between the requirements of the national customers (MODs or Purchasing Agencies) and the viable options the industry can offer to mitigate the adverse effects of obsolescence for defense material with emphasis on the extended use of COTS.

Twenty years ago the main technical discussion topic within the defense industry was technological progress and achievements. Today we have become prisoners of this progress and are increasingly unable to keep pace with the technology. Instead we have to deal with the antithesis of progress – outdated or obsolete components. Obsolescence concerns suppliers and customers in different ways but in any case the result is painful since obsolescence has adverse effects on our business. There is no way to defeat obsolescence, it has properties like gravity, it lurks everywhere in our electronics world and it will stay. We have to accept it like a law of physics and as a fact of our professional - and our private - life. When I studied electronics engineering in the sixties, I used to make some money by repairing TV sets. My stock of spares to repair a hundred or even more different sets easily fitted into a briefcase and consisted of some 20 electron tubes and a handful of resistors and capacitors. Have you ever tried to get your 5 year old Korean Video Cassette Recorder repaired? – an ambitious task which will frustrate you quickly and will probably result in the acquisition of a new one for 200 bucks or even less. In all probability you would not even have tried since you wanted a new one anyway.

Let me get this straight from the very beginning. Obsolescence is a very big problem for the supplier industry. It has not been created by the industry – as some may see it – as a welcomed source for additional revenue.

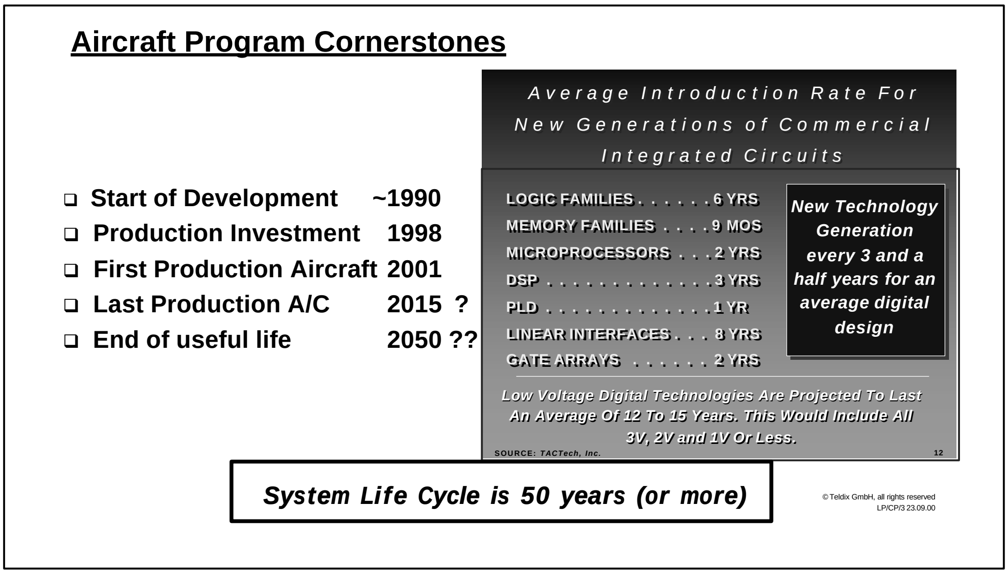


Figure 1 - Typical Aircraft Program and Semiconductor Life Cycles

To analyze the task at hand we have to have a look at the life cycles of both, our advanced weapon systems and the microelectronics driving it. Figure 1[i] clearly illustrates the conflict we are in.

Whereas the life cycles of our weapon systems have become increasingly longer and exceed in many cases 50 years, the introduction cycles of new commercial microelectronics families average approximately 2 to 4 years, for memory devices they are as short as 9 months. And the trend is continuing.

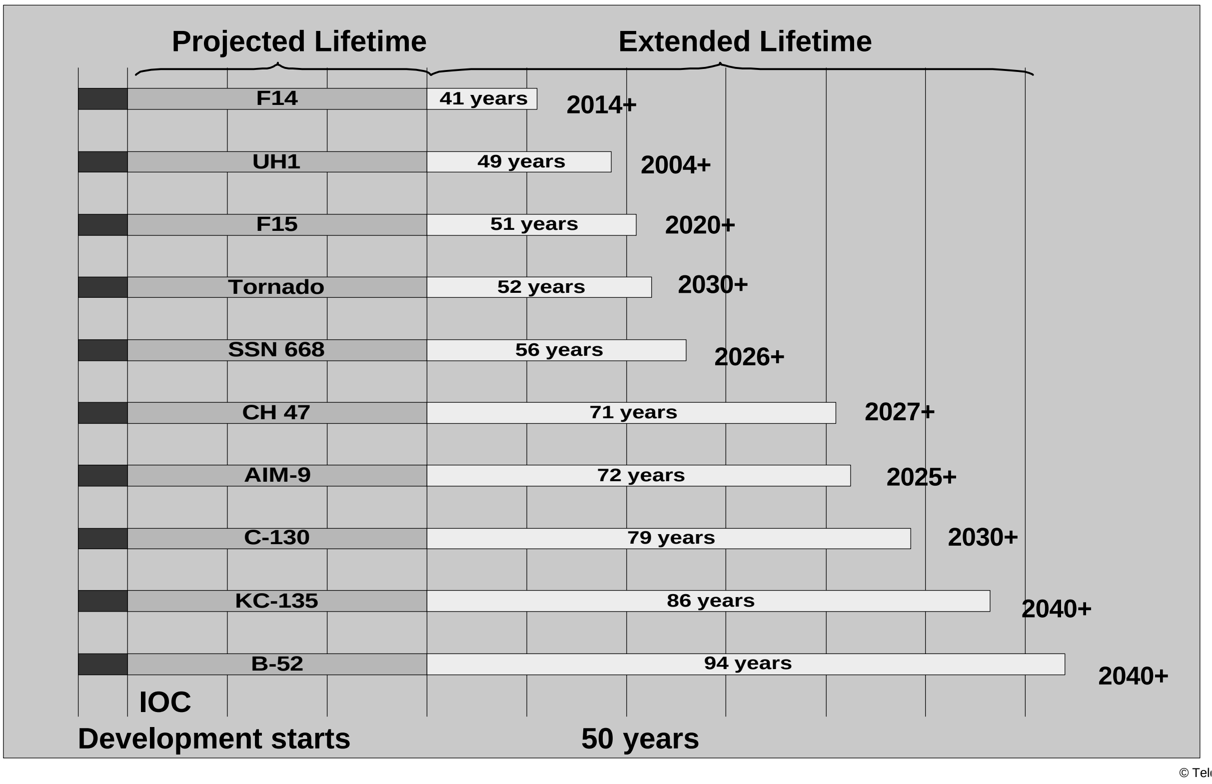


Figure 2 – Weapon System Life Cycles

Figure 2 shows the expected life cycles for selected weapon systems [ii]. If we look at these figures and on the other hand at the life cycles of the semiconductor devices driving our equipment, it becomes apparent, that we have to deal with a very complicated situation.

Leaving the technical aspect aside for a moment, what does this mean to our business? It clearly shows, that our nice and shiny high tech equipment developed today, introduced into service in 3 to 4 years time or even later depending on the weapon system, will become unsupportable in 2010 or even earlier. We will simply not be able to procure the necessary parts for production and more important for product support regardless whether we rely on commercial or military components. The only difference will be, that with the use of commercial components, our problems will materialize earlier because of the shorter life cycles. We all know the sarcastic definition of obsolescence with respect to military equipment:

If it's in production, it's obsolete,

or even worse:

Once it's in production, it's obsolete

Yes of course, the industry has developed crutches to survive in this unpleasant environment, namely

- To make last time, life time or bridge buys to protect production programs and to support products through the later part of their life cycle. All three prone to error and are the antithesis to modern business strategies. They create inventory which may never be used and may finally have to be scrapped.
- To purchase parts from aftermarket suppliers – at a cost
- To search for surplus inventory using professional services such as partsbase.com, GSX, LoKtor or others for product support

But whatever we do, there is no basic difference in the employed processes, commercial part or military, the effort and the results are in general the same and the described options are really only crutches.

Let me tell you about the cruelties of the obsolescence world. A few years ago, we were notified by an ASIC manufacturer, that the production process of one of our ASICs was going to be obsoleted shortly and that we could place a last time buy order, which was what we did. Since we were not in urgent need for the parts, we asked the supplier to store the dies for us. When we finally retrieved the dies from the nitrogen and wanted them packaged, we discovered , that in the meantime the package had become obsolete as well, making a complete re-layout of the respective CCA necessary. Now you may say, that a top notch ASIC supplier would take care of that. Yes, you are right, but we learned the hard way that you cannot buy insurance.

In another case, we were notified by a distributor, that a critical part had become obsolescent, and that we had exactly 6 working days to place our last time buy order. To make it worse, the notification arrived on Dec. 15th with many people already gone for season vacation. We should also bear in mind, that decisions on last time buys and bridge buys need some careful considerations with respect to product support and it is usual practice to agree such buys with the customer, unless we are prepared to accept the full commercial risk. It also clearly illustrates, that the issue of last time buy notifications is a process, which is not very disciplined, and it is to be expected, that it is even less disciplined with commercial components (figure 3 [iii]).

Obsolescence Notification

- **Military Components:**
  - ⇨ **Registered letter to direct customers buying within 5 years**
  - ⇨ **6 months order entry**
  - ⇨ **GIDEP**
  - ⇨ **WEB**
- **Commercial Components:**
  - ⇨ **Letter to direct customers buying within 2 years**
  - ⇨ **3 months order entry**
- **No notification to distribution customers !**

Source: Texas Instruments

Figure 3 - Obsolescence Notification

Since then we have improved our obsolescence management considerably, with the result, that we have much better visibility today. Nevertheless, the obsolescence problems still have to be resolved one way or the other. We do have better diagnostic tools today, but there is still a very sick patient out there and no adequate therapy for a final cure.

But let me get back to my initial thesis. Is the attempt to mitigate obsolescence by the use of commercial components a contradiction in itself?

As we all know, the use of commercial components in military equipment creates its own set of problems as outlined in figure 4.

COTS Problems

- **Short life cycles**
- **No disciplined obsolescence notification process**
- **Environmental Conditions**
  - ⇨ **Temperature / Altitude / Humidity**
  - ⇨ **Nuclear hardening**
  - ⇨ **Vibration**
  - ⇨ **Shock**
  - ⇨ **EMC**
- **Shrinking parameter margins**
- **Shrinking structure width**
  - ⇨ **Electromigration**
  - ⇨ **Dielectric breakdown**

Figure 4 - COTS Problems

We have to deal with extreme environmental conditions like high and low temperature, gun fire vibration, shock and sometimes nuclear hardening – just to mention a few. In some cases we have to drive the devices outside the specified performance envelope with the risk of unexpected and unknown side effects.

In other cases the performance envelope of the component may not even be specified, for example Nuclear Hardness. In other cases again we may decide to up-rate our devices, which is in itself a highly disputed practice. The up-raters claim, that this is the only way to happiness whereas the semiconductor industry strictly opposes this practice with good reasoning.

The use of Commercial Off The Shelf items or COTS in military equipment has been sparked off by the **PERRY DIRECTIVE** in 1994. Some of Dr. Perry's original wording is given figure 5.

After careful analysis of the text we can extract 4 major objectives, which are:

1. Quote *... that we're going to rely on performance standards instead of relying on mil specs to tell our contractors how to build something ...* unquote.
2. Each system is to use the lowest grade of component, that would meet the environmental and performance requirement of the system,

Figure 5 - Perry Directive

"... We are going to rely on performance standards .... Instead of relying on mil specs to tell our contractors how to build something .... There will still, of course, be situations where we will need to spell out how we want things to be built in detail. In those cases, we will not rely on mil specs but rather on industrial specifications... In those situations where there are no acceptable industrial specifications, or for some reason they are not effective, then the use of mil specs will be authorized as a last resort, but it will require a special waiver."

Secretary of Defense William J.Perry, press conference June 29, 1994

3. Mil specs and standards should only be used as a last resort
4. Remove requirements, which do not add value.

The Perry Directive is one of the most misunderstood and misinterpreted directives in our business. When you read it, you know why, since there is a lot of room for misinterpretation. It does not say we must use commercial components and it does not say, that all military specification are void either.

In the wake of the Perry Directive our customers increasingly insist on the use of COTS to keep up with the edge of technology and concurrently reduce cost. At the same time industry is faced with the problem, that despite all the encouragement to make extensive use of COTS the necessary relaxation of the associated implementation requirements in our specifications - how we have to build something as Dr. Perry has put it - have not yet come along. In addition we still have to meet the tough environmental requirements already mentioned regardless of the Perry Directive. As a consequence the industry ends up between the rock and the hard place and has to accept a high technical and commercial risk when acquiring defense contracts. This situation is further complicated by the customer's – legitimate? - expectation, that due to the use of commercial components, the equipment acquisition and support cost should drop significantly.

All this is happening in an environment of steadily diminishing supply of military components, and rapid innovation cycles for commercial component families, without leaving any significant purchasing power for the equipment supplier industry in a market, which is primarily driven by telecommunication, the internet and PC industries and consumer electronics. Figure 6 illustrates the semiconductor market as of 1999 [iv].

In a press release[v] the Semiconductor Industry Association announced in February a worldwide semiconductor sales figure of 149 billion US dollars for 1999, which was an all time record. In the same press release an expected growth in excess of 20 % for 2000 and 2001 was announced. And the SIA June figures[vi] clearly confirm this trend with an actual growth of 48.1 % over the 1999 figures (figure 7).

The drivers for the semiconductor industry are changing rapidly from the PC industry to the telecom and internet appliances.

Commercial vs. Military Semiconductor Market

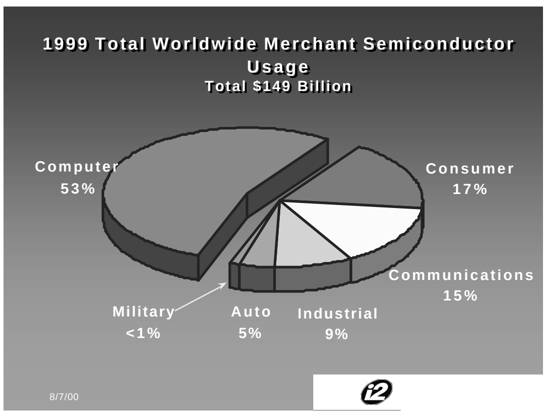
- **Commercial Market**
  - driven by Telecom, Internet and PC Industries
  - record 149 bn$ sales in 1999 (up 18.9%)
  - 20 % growth expected in 2000 and 2001 led by DSPs, Flash Memory, dedicated telecom Circuits and Microprocessors
  - More dedicated, less general purpose microcircuits
- **Military Market**
  - no drivers, niche market
  - little buying power despite volume of approx. .6 to 1 bn. $ / yr.
  - shrinking volume
  - diminishing number of suppliers
  - diminishing number of components

Figure 7 - Commercial and Military Semiconductor Market

Figure 6 - Semiconductor Market

Semiconductor Market

- **Military Market Share**
  - **1960 >50%**
  - **1976 17%**
  - **1986 7.5%**
  - **1996 0.7%**
  - **2000 <0.4%**



- **Reduction of commercial interest in military semiconductors due to**
  - **Perry Directive**
  - **Declining military budgets**
  - **Excessive growth of commercial market (telecom, internet, PC)**

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While in 1999 approximately 200 million cell phones were sold, the SIA is expecting a market volume of one billion cell phones in 2003[vii] quintupling the market volume in four years. What significance has the continuously shrinking military semiconductor market of 600 million to 1 bn US $ / yr. in this context despite the volume in itself being impressive?

To summarize let's have a look at the different drivers for obsolescence and the use of COTS on the other side. It appears, that both issues have little in common, except for market factors. The use of COTS is mainly commercially driven, whereas obsolescence is basically technology driven, and is applicable to COTS as well. (figure 8)

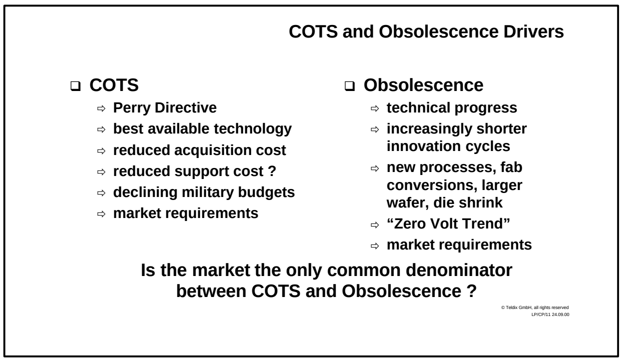

Figure 8 - COTS and Obsolescence Drivers

As a result my first and rather trivial theorem is:

Commercial components are not a solution to the obsolescence problem, they are part of the problem.

But still, what is the solution to our Obsolescence problem?

Let's get back to Dr. Perry for a while, does he help us with our problem? What do the four objectives identified earlier really mean with respect to our obsolescence problem?

As we remember, Dr. Perry's first objective was:

Use performance based specs.

What does that mean?

A first step on our way to deal more effectively with obsolescence may be the adoption of a black box approach for our equipment, similar to the practice in the civil aviation community. That means, that the specification defines only the required performance, the environmental conditions and the interfaces, but no implementation details. What is inside the box should be left to the supplier. That includes bold concepts like technology transparency and technology insertion for the equipment in question, with the result of having different build standards for the same specification, all of which will satisfy the specification in all aspects. Yes, I agree, there are lots of arguments not to do this, such as qualification and re-qualification problems, support, configuration issues, customer software and other problems as listed in figure 9.

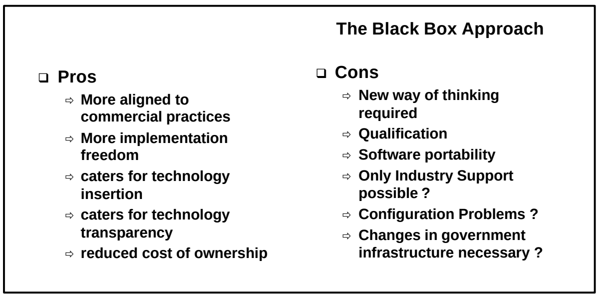

Figure 9 - The Black Box Approach

This does not mean, it cannot be done, it just means that we have to be more creative in the future in dealing with these issues. This will require close cooperation of all involved parties from government to industry. As to our obsolescence problem, the industry might be able to compensate some obsolescence non recurring cost with recurring savings which may become possible by value engineering and the use of more advanced technology throughout the life cycle of the equipment. Here we may be able to learn something from the civil aviation. They must have a very similar set of problems, how do they cope with them?

Dr. Perry's second objective was:

Each system is to use the lowest grade of component, that would meet the environmental and performance requirement of the system.

This objective amends nicely what has been said for objective number 1. It will remove the requirement to use the highest quality grade of components, freeing the industry to select the quality level it sees fit to fulfill the specification. This will most likely have a positive impact on cost, but will not help much with our obsolescence problem.

Dr. Perry's third objective was:

Mil specs and standards should only be used as a last resort.

I am under the impression, that this objective has gone totally unnoticed within our customer community, at least in Europe. How nice would it be, if we wouldn't have to read a hundred or more mil specs with every RfQ.

Instead I find more and more mil specs in the requirements which have officially been cancelled already or which are totally irrelevant, nevertheless being a diligent program manager, I have to comply somehow and read all of it.

However, the objective in itself is a good one and we should all work hard, to enlighten our customers, that less may be more.

Now some may say: “What do I care about the Perry Directive, I am here in Europe and have nothing to do with the US Government Acquisition practices”. This may be true, nevertheless I personally think, this is a rather ridiculous argument, since we did not hesitate at all to accept the excellent system of mil specs and standards during the cold war. Now, as the US DoD relies more and more on COTS and has started to send mil specs and standards into retirement, we Europeans won’t let go.

Dr. Perry’s fourth objective was*:*

to remove requirements, which do not add value.

In my humble opinion this is simply common sense, although this - as number 3 above - has apparently gone unnoticed by our customers. Everyone in the industry familiar with government acquisition processes must have asked himself over and over again: “ why the hell do they want this”. In many cases the answer is simple: It was somewhere in the model text the author has used to compile the specifications or the request for quotation.

Again, the removal of non value adding requirements is a great concept and would alleviate many problems in fielding new equipment, it may also help to reduce cost and time to market, it will, however, not help to battle obsolescence.

That leaves us with objective number one, the black box approach and the adoption of civil procedures. What other options do we have to alleviate the problem? One way that has been generally accepted in many defense programs, is to align the removal of obsolescence with planned weapon system upgrades. In order to enable the industry to do that, a much better visibility as to the planned upgrade path of the weapon system has to be provided. This again requires very close cooperation between government, Weapon System Contractor and supplier industry.

I have to admit, this might only be a first small step and is still far from being a technical solution. And we need more than that. We have to have both, a stable and sound technical as well as a commercially viable business solution. We need, however, to start somewhere.

And beyond this?

In my effort to prepare this paper I searched the internet for information on the subject and to my surprise I found plenty of information out there. Actually it was much more information than I was able to digest in the limited period of time. In the US alone I found more than 100 web sites and 34 different projects dealing with the obsolescence problem, most of them sponsored by the DoD or the services. In addition there are dedicated DMSMS program organizations or management teams in place to deal with obsolescence for a specific weapon system such as for the B2 Bomber. Much work has been done in this field by the US Air Force Materiel Command, the Defense Logistic Agency (DLA), the Defense Microelectronics Activity (DMEA), the Government Industry Data Exchange Program (GIDEP), the Generalized Emulation of Microcircuits activity (GEM) but also by private enterprises such as TacTech now I2 and others. None of these activities is trying to solve the obsolescence problem once and for all since there is no such solution. All activities are geared to defining and providing tool sets to handle obsolescence problems as they occur.

What can be learned from these activities, which again are all located in the US, is, that we need to approach the problem on a much higher level, with all entities involved, be it industry or government, working much more closely together to keep the problem under control. The progress made in the US is in my opinion mostly to be attributed to the fact, that the Department of Defense and the services with their organizations have recognized very early the grim facts of obsolescence and have proactively promoted a variety of activities to jointly overcome the problem, instead of making obsolescence simply a problem or even a liability of the equipment supplier industry. When we review what has been achieved in the US already, I feel, there is a lot of work – and education - to be done in Europe to catch up. And in doing so, we should accept the experience of others instead of re-inventing the wheel. Are there already answers available, which we do not use, simply because we do not know about them?

The way we are presently trying to manage obsolescence is bottom up, everyone solves his little problem in his little box which means the same problem is being solved over and over again. We have to come up with a top down approach to be more efficient. This requires bold moves and the implementation of what I call “wild ideas” as shown in figure 10. May be some of those ideas are not so wild at all, but someone has to take the lead, and this cannot be the supplier industry. Again, what we need is a top down approach.

Wild Ideas.....

.....or not so wild at all

- **Cross Corporation Obsolescence Management**
- **Joint Purchasing and Warehousing**
- **Shared Data Warehouse**
- **Weapon System Coalitions to battle Obsolescence (e.g..teaming of F16, C17, B1-B, JTIDS, MILSTARS, AWACS and JointSTARS in the USAF)**
- **Is a NATO Obsolescence Management Organization too long a shot ???**
- **Can we get help somewhere else, use the experience of others?**
- **There is plenty of information and experience out there, we just have to go get it (and use it).**
- **Who is taking the lead ???**

Figure 10 - Wild Ideas

But let me come back to the question of using commercial components in military equipment. As I have outlined already, the use of COTS components is in my opinion no way to mitigate the obsolescence problem, since COTS is subject to obsolescence itself, and as we are all aware, life cycles are shorter and the obsolescence notification process is less disciplined. No matter what, the supplier industry will be forced to make more and more use of commercial components simply because of the continual erosion of the supply base of military components. We will have to deal with even more difficult obsolescence problems in the future. In addition it must be said, that the trend towards commercial components is not limited to the battle between plastic versus ceramic packages. The use of COTS components in military applications may create an additional set of problems in the future which may for instance be attributed to the consistently shrinking structure width of microcircuits as a result of the demand from the telecom industry and the trend towards zero volt supply voltage. This may result in tremendous EMC problems for our equipment.

But isn't the controversy between military and commercial a controversy between extremes. There is not only black and white, there are shades of gray as well. Within the last 10 years QML has gained a lot of attention and importance within the defense industry. Many of the big names, who dropped out of the military semiconductor business, have certified their production lines to meet the QML requirements. Today more than 30 semiconductor manufacturers have qualified more than 300 production lines and the trend shows a stable growth. In short QML is not just commercial, but is simply better. Actually QML is best commercial practice. It is more expensive than "commercial", but is more disciplined, it meets most of our stringent requirements for military equipment and it has longer life cycles. However, QML is vulnerable to obsolescence as well, and the use of QML does not solve our obsolescence problem either.

And here comes my second theorem, which is rather trivial again:

Although the use of commercial components does not help to mitigate the obsolescence problem, we have to use them anyway to mitigate the eroding supply base of military components.

All in all the use of commercial components in our military systems is - as mentioned before – still a big problem in itself. It requires more research, diligence, cooperation, and a lot of common sense. QML may help - as long as it lasts.

On the other hand, obsolescence management is – as we have all become painfully aware – a tremendous task in itself, requiring its own infrastructure and resources. And it has to be done regardless of the component quality level.

Summary

- **The use of Industrial Grade Components in military equipment will become a necessity, due to the diminishing supply base for military components**
- **The use of Industrial Grade Components is not a way to mitigate obsolescence problems ... <u>to the contrary</u>**
- **The use of Industrial Grade Components is an additional challenge to obsolescence management, which has to be accepted by the industry.**

Figure 11 - Summary

In summary my conclusion is, that in the long run the use of commercial components in our systems will become a necessity but for other reasons. It is not a way to mitigate obsolescence, it is an ***additional*** challenge to obsolescence management. Still, there is no other way than to accept this challenge, since our military semiconductor supply base will continue to erode.

About the Author:

The Author is a German national and holds degrees in electronic engineering and business administration and has more than 30 years of international experience in the defence industry. Prior to joining TELDIX he held various program / project management positions at LITEF, Litton Aero Products, AEG and DASA. He joined TELDIX GmbH, an affiliate of Litton Industries in Germany, in 1990 where he is today Head of Program Management and responsible for all defence programs. In his function he is extensively involved in the company's Eurofighter Typhoon Business.

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[i] Graphics with friendly permission of TacTech / i2
[ii] Concept Paper: Virtual Parts Supply Base, 15. Jan. 1998
[iii] Texas Instruments
[iv] Graphics with friendly permission of TacTech / i2
[v] The Semiconductor Industry Association, 9. Febr. 2000
[vi] The Semiconductor Industry Association, 3.Aug.2000

New Approaches to Processor Lifecycle Management

October 2000

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Summary: There is a growing discontinuity between the semiconductor supply chain and the requirements of military programs to support equipment in the field for long periods of time - typically for 15 years or even longer. This isn't news any more, it was a natural consequence of the COTS Procurement Initiatives and the shift in focus of the semiconductor supply industry, started early in the 1990s, to much larger and ever more lucrative markets. While COTS was embraced enthusiastically at the outset by our community, some of the real issues are only now beginning to come home to roost, tainting COTS as a standard for doing business. This is apparent through the performance of some suppliers, particularly in their attitudes and commitment to obsolescence and real lifecycle management.

This paper has been written from the perspective of a COTS, open architecture, board-level supplier and is intended to provide insight and guidance for the selection and management of a supplier when considering various options of overall system lifecycle management.

COTS: definition: "***Commercially available products, available from a published catalog and price list. The supplier will have absorbed the IR&D costs and will own the IPR. Performance of the product is as stated in the supplier's specifications***". This pure definition makes no claims as to the ruggedness of the product, nor to its suitability for deployment in the final, end-use application. The integrator must make the selection of product and supplier based on his own and the supplier's performance specifications. COTS procurement is not descriptive of product quality or fitness for purpose, it is a ***process*** which must be adopted to achieve the true benefits of COTS.

Program Phases: Systems integrators ideally need to maintain technology continuity between the various phases of their programs, from ATD (Advanced Technology Development), through EMD (Engineering Manufacturing Design), LRIP (Low Rate Initial Production) and Production. COTS products such as VME have had a real and visible impact on reducing the length of these cycles, particularly for non-mission critical or benign environment programs where the jump has been made, in some cases, directly from ATD to full production and deployment. However, the life of individual components used in a typical VMEbus product, often as short as 18 to 24 months today, may not be long enough to support even two consecutive phases of program development.

Lifecycle Management, Early Commitment is Required: Given the obsolescence challenges, total Product Lifecycle Management is the only way to effectively bridge the widening gap between customers' and end-users' needs and our industry's ability to deliver effective and maintainable solutions. Lifecycle management is just what it says. It starts from inception of a new product idea and doesn't end until the last customer has sent his last product back for repair. The first step starts with new product design by implementing a Component Selection Procedure. This means understanding your suppliers and their market dynamics, and working with them to ensure acceptable parts longevity. The ideal situation is to only deal with suppliers who offer a reasonable promise of longevity. Unfortunately, this is not always practical especially when it comes to the leading-edge technologies that evolve very rapidly.

At this stage the board level supplier can provide valuable engineering and technical input during the integrator's system design and evaluation process. There are usually parts of a system that are fairly unique to the platform or to the military environment. Since there is a thriving, though small, semiconductor supply industry still serving, for example, the needs of specific military interfaces, it is unlikely that these areas of a system design will cause severe obsolescence problems down the line. The vulnerable areas of a system design are those that feed off rapidly-evolving technology streams such as those driven by the desktop, telecommunications or consumer goods. Typically, these products will be processors (or single board computers), graphics, memory and DSP boards. In their native market environments these technologies can be expected to have life spans of 1 to 3 years. This

Paper presented at the RTO SCI Symposium on "Strategies to Mitigate Obsolescence in Defense Systems Using Commercial Components", held in Budapest, Hungary, 23-25 October 2000, and published in RTO MP-072.

is unacceptable for the 15+ year lifecycles of major projects. However, these technologies are setting the standards for performance and functionality and have become the targets for new and innovative approaches to product and program lifecycle management.

Lifecycle Management, Two Options: There are still only 2 basic philosophies for program lifecycle management. These can usually be developed into hybrids if necessary to suit the individual program's needs:

Traditional: Freezing the design at the end of the EMD phase is the traditional strategy for dealing with continuity of design and obsolescence. This offers many advantages with respect to control and total interchangeability throughout the program but has serious disadvantages in today's environment.

Advantages:

- Total design control is achieved.
- Modules of a like kind are fully interchangeable.
- The performance of the system is totally predictable.

Disadvantages:

- The design is fixed and therefore inflexible when the time comes to introduce a new feature or capability.
- Some components will go obsolete between the time of EMD, LRIP and full Production with no funding source available for their procurement. It is unusual for funding to be available at EMD or LRIP to buy the full program lifecycle requirements (5 year production plus 15 year support).
- Systematic failure of one single part can make the whole system vulnerable to its effect.
- By the time full production status is achieved the technology is often outdated and does not meet the then current performance standards.

Traditional long term program support requires a Supplier Program Management infrastructure to handle parts control, redesign as required (either device substitution, replacement with ASIC or total product redesign) and long term inventory management. Tailored lifetime sustainment programs need to be created to meet the ongoing needs of specific programs. Despite the care placed upon component management, too many programs are getting trapped into maintenance philosophies that are at the mercy of single-sourced components, many of which are already obsolete. O&M budgets can be used for program sustainment through the redesign of assemblies using newer parts to mitigate against obsolescence, but the wheel will inevitably turn again and no advantage is achieved in terms of either enhanced capability or performance. This is spending just to stand still – no improvement in the performance or functionality of the equipment will be gained unless a major redesign is undertaken, which may even exceed the cost of the original procurement.

Technology Insertion: An alternate approach that is developing into an industry standard is Open Architecture, Functional Partitioning and Technology Insertion. This three-cornered strategy can be used to define the future lifecycle requirements of a system:

Open Architecture: In this case, based on the VMEbus, but could be CompactPCI or high speed serial architecture such as Fibre Channel or Firewire. It provides vendor and technology independence plus a long-life backbone architecture that continues to evolve while maintaining backward compatibility.

Functional Partitioning: This involves the designer's use of the modularity afforded by the chosen open architecture to functionally partition the system into a) platform-specifics with long life span and b) technologies with rapid evolution (i.e. SBCs, graphics, DSP and others).

Technology Insertion: This means planning to insert improved technology in batches through the production and support life of the program.

Advantages:

- The system backbone is future-proofed by the extensive commercial interest in the continued growth and development of VMEbus.
- The system can be upgraded to provide greater performance or functionality as the threat changes (unlike proprietary systems with spare slots which always proved to be unusable at an economic price) and finally the cost/performance of the system will improve with time.
- Moore's Law will prevail meaning that the cost of each new generation of product will continue to decrease.

Disadvantages:

- Systems built in batches with different configurations will present some additional logistics overhead in record keeping and inventory
- Recertification of safety-critical functions may be required.

This is the model that many of today's integrators are adopting to protect against future obsolescence. One example is Boeing/GDIS (General Dynamics Information Systems) and the OSCAR (Open Systems Core Avionics Requirement) program which is planning regular insertions of increasingly powerful Single Board Computers (SBCs) into their systems for deployment on AV-8B, F-15 and F/A-18E/F.

Technology Insertion will be supported by many COTS suppliers in future generations of their product line evolution. This requires serious commitment to continuously update and replace vulnerable product lines. This is very different to the single-point solutions that used to be acceptable for the *traditional* controlled development program.

But Technology Insertion cannot just happen. Each new program should evaluate the benefits and make plans to adopt it as a standard from the outset:

- Make control loops independent of processor performance.
- Never hand-optimize code for performance. Make the application independent of hardware specifics - use middleware to abstract any hardware features.
- Further abstraction can make the application independent of processor type - will require an excess of performance in all situations.
- Plan for the use of the increased capability offered by technology insertion.

Program Considerations: The lifecycle management strategy chosen depends upon the nature of the program: the size of the production run, the length of the full production cycle, the anticipated lifespan, the intended maintenance philosophy and so on. As an example, a low volume program with a relatively short timespan from the introduction of the first unit to the delivery of the final unit can often live within the anticipated *product* lifecycle of the chosen supplier. In this case it is likely that all units can be identical and that spares for the deployed lifetime of the program can be procured at the same time as the production units. This would be a candidate for the consideration of the traditional methods of management. But the downside must not be ignored: once the system is fielded its functionality and performance is fixed for its entire lifecycle, no ability to react to developing countermeasures, or changes in politics, or strategic redeployment.

Consider, however, an alternative scenario which is typical of a major vetronics (vehicle electronics) or avionics procurement program. In this case there is often a lag between ATD, LRIP and EMD phase as field trials and exercises are used to shake down the final performance envelope and functional requirements. A typical production program might encompass 1,000 vehicles or more spread over a 15 year period. Look at the M1A2 Main Battle Tank, Eurofighter Typhoon, F-16 or F/A-18 programs. Translate that into buying power, for example, for microprocessors. Even if each platform had 50 processors of the same type distributed among its various subsystems, that's only 5,000 pieces per year. Not enough to capture the attention of today's microprocessor manufacturers.

The 10 year production period itself is incompatible with today's fast paced technology turnover: the desktop PC is barely 10 years old and look how that has changed. This is a prime example of where there has to be a series of technology insertions through the production life just to ensure continuity of supply. In this case the program will be divided into a number of tranches or blocks, each representing a 3 to 5 year production standard. Using technology insertion without a major rewrite and recertification of the platform at each step is the obvious solution (see Figure 1). Each new block should also be cheaper than the previous – driven by Moore's law.

Technology Refresh: This is a derivative of Technology Insertion. In the previous example of a large production program, every new technology step is made 100% backwardly compatible with the previous so that older technology can be refreshed by swapping out the old for new whenever maintenance action allows. Technology refresh requires that the supplier is very strict about configuration management to guarantee this swap-out capability through the inclusion of the inevitable minor changes over a product's life.

Future Directions for COTS Vendors: Technology Insertion is the strategy that COTS suppliers will support through future generations of their product lines. This requires a commitment to continuously update and replace. There is a very big difference between ***program*** lifecycles and COTS ***product*** lifecycles. A COTS product has a lifecycle much like any other commercial product (i.e. design and development, introduction and capture of design wins, full-scale production, maturity and finally retirement) but with extended timescales.

Product Lifecycle Planning: COTS suppliers today must preplan their products' lifecycles to guard against obsolescence – very often components become obsolete or unobtainable in the very early stages, while the product is still capturing new design wins. Lifetime buys are often the only way to guard against obsolescence, yet how can the supplier estimate the eventual requirements for full scale production and lifetime support this early in the cycle? This issue was not considered seriously enough by the procuring authorities in the changeover to COTS-based procurement. COTS products will go obsolete during the development timescales of a program, yet there is no funding provision available to support the supply base. The only way for the supplier to protect his investment is to preplan for a minimum lifespan, a minimum production volume requirement *and* the introduction of a replacement product (for technology insertion) as early as possible. In this way the integrator and end-user are assured of a continuous stream of evolving yet functionally compatible products. A reasonable timespan today for a 'hot'

product is 5 years from design and development to maturity.

Programs should ideally aim to be in-phase with their chosen supplier's *product* lifecycle. Suppliers must advise their customers of a product's relative position on its lifecycle curve – the maximum benefit can only be obtained when full scale program production coincides with full scale product production. Suppliers today are learning to share these product lifecycle curves and their future roadmaps with their customers to everyone's benefit.

COTS product lifecycle management is still very much in a state of flux and only part of the way up the learning curve. Traditional program requirements cannot be abandoned overnight, so the ideal is to be able to support both the old and the new during a long period of transition. Many of today's COTS VME suppliers do not appreciate the need for either strategy, usually following technology curves with little regard for the program lifecycle. Even though the root cause of rapid component obsolescence is outside of our direct control, there is much that can be done in partnership, between supplier, integrator and end-user to mitigate the effects. Reviewing the overall system architecture and designing for Technology Insertion, hardware abstraction and program/product synchronism hold great promise as methodologies for the future.

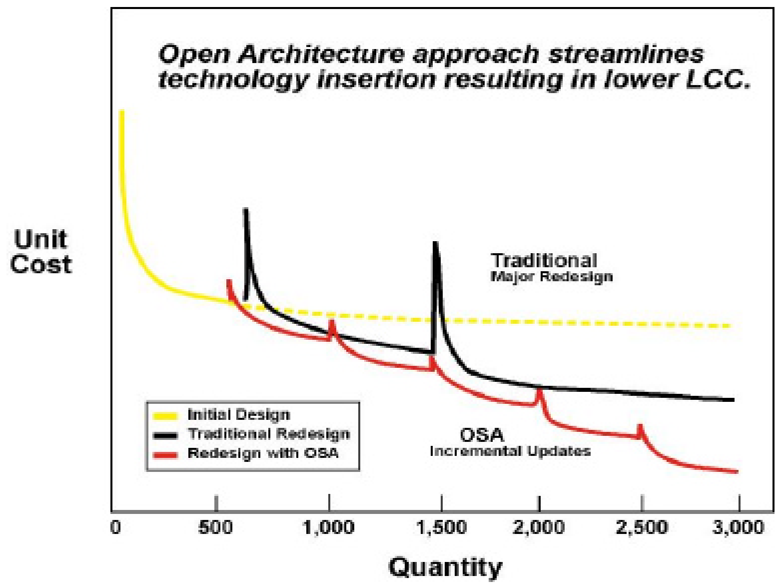

Figure 1: Cost curve of large program based on regular technology insertion

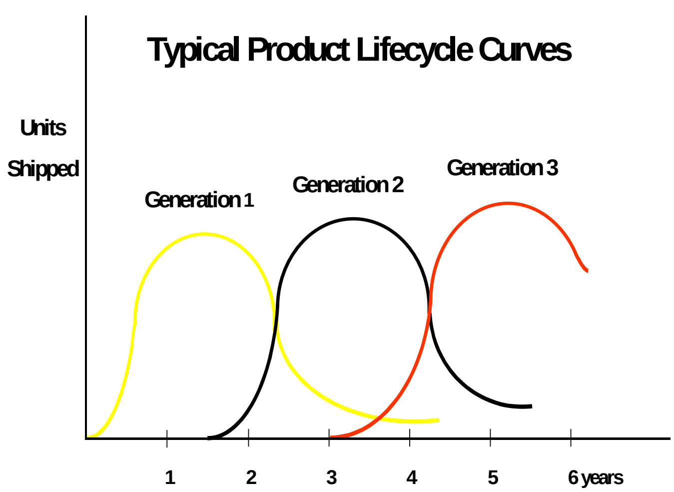

Figure 2: Product Lifecycle curves

Consequences for the design of military aircraft systems due to integration of commercial electronic components in avionics

(October 2000)

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1. SUMMARY

The time when aerospace requirements and investments initiated micro-electronic components development has passed.

Industries like Telecom and Personal Computer invest many times more than aerospace with huge economical, performance, size, mass, packaging and assembly improvements.

The lifespan of these developments in the market is very short.

The Life Cycle Costs for keeping up avionics design with special ruggidised components and designs is likely to be higher than to adapt a military aircraft and their periphery to avionics with non-ruggid electronic components.

There are technical solutions available to adapt the military avionics environment to the requirements of non-ruggid electronic components ad designs.

This paper describes the relevant environmental aspects in nowadays military aircraft designs, which have to be considered and their relation to non-ruggid electronics.

Further on this paper describes some possible modifications of military aircraft designs to cope with the environmental requirements of non-ruggid electronics.

2. ADVANTAGES OF USING UNSCREENED ELECTRONIC COMPONENTS AND DESIGNS INSIDE A MILITARY AIRCRAFT

The immediate and unlimited access to the actual complete electronic market with its very fast technological progress of electronic components, Printed Circuit Board layouts, computer architecture, SW design and IT aspects allows:

* a fast and flexible improvement of mission capabilities,
* an avionics mass and volume reduction (mission performance),
* an avionics upgrade cost reduction,
* an avionics Life Cycle Cost reduction,

* an extended competition,
* a development time and qualification test reduction,
* a extended use of complete off the shelf HW and SW solutions,
* an increase of cross-usability of HW & SW in different products and programmes,
* a solution for the obsolescence difficulties in military programmes.

3. ACTUAL ENVIROMNENTAL REQUIREMENTS FOR MILITARY AVIONICS

Following examples of quantified environmental requirements are actual typical for military avionics:

Temperature:	Operating:	- 40° to +70°C
	Non-Operating:	- 60° to +90°C
	T-Changes:	up to 40 K/s
	Supply air:	-40° to +54°C with 3.5kg/kW/min
Pressure:		3 to 115 kPaa
Pressure Changes:		6 kPa/s increasing 4 kPa/s decreasing
Humidity:	absolute	0 to 30 g_{WATER}/kg_{AIR}
	relative	0 to 100 %
Sand / Dust:		up to 20 g/m³
Vibration:	Functional:	up to 0.10 g²/Hz
	Endurance:	up to 0.42 g²/Hz
	Frequencies:	10 to 2000 Hz
Acceleration:		up to 13 gn
Acoustic Noise:		up to 150 dB
EMC:	EMC:	> 200 V/m
	NEMP:	> 50 kV/m in ns, 50 A
	Lightning:	> 10 kA
Power Supply:	115/200 V ± 10% , 400 Hz ± 5%	
Power Interrupts:		up to 30 ms

Paper presented at the RTO SCI Symposium on “Strategies to Mitigate Obsolescence in Defense Systems Using Commercial Components”, held in Budapest, Hungary, 23-25 October 2000, and published in RTO MP-072.

4. ACCEPTABLE ENVIRONMENTAL CONDITIONS FOR NOT RUGGID, UNSCREENED CIVIL ELECTRONIC COMPONENTS AND DESIGNS

Following examples of quantified environmental conditions are accepted by not ruggid, unscreened civil electronic components and designs:

Temperature:	Operating:	+10° to +30°C
	Non-Operating:	0° to +70°C
	T-Changes:	no data found
	Supply air:	0° to +55°C with 1.5 m/s
Pressure:		70 to 115 kPaa
Pressure Changes:		no data found
Humidity:	absolute	no data found
	relative	0 to 50 %
Sand / Dust:		clean environment
Vibration:	Functional:	up to 0.002 g²/Hz
	Endurance:	no data found
	Frequencies:	5 to 500 Hz
Acceleration:		up to 4 gn
Acoustic Noise:		no data found
EMC:	EMC:	3 V/m
	NEMP/Lighting:	no data found
Power Supply:	220 V ± 10%, 50 Hz ± 3%	
Power Interrupts:		no interrupts accepted

The comparison of the actual military environmental requirements with those of civil electronic components and designs show significant discrepancies.

If not-ruggid, unscreened civil electronic components and designs shall be used inside military avionics, the military aircraft has to be adapted.

5. ADAPTATION OF MILITARY AIRCRAFT TO THE NEEDS OF NOT-RUGGID, UNSCREENED CIVIL ELECTRONIC IN MILITARY AVIONIC

5.1 MILITARY AIRCRAFT ASPECTS, WHICH INFLUENCE THE ENVIRONMENTAL CONDITIONS OF MILITARY AVIONICS

Following military general aircraft systems have an interface to avionics systems.

* Environmental Control System
* Electrical Power Generation and Distribution System
* Data Link
* Mechanical Integration (Aircraft Structure, Avionics Racks, Module Housing)

Following further logistical aspects influence the environment of the military avionics

* Handling and Maintenance concept
* Testability concept
* Storage concept
* Aircraft Ground Equipment

5.2 ENVIRONMENTAL RESPONSIBILITIES

These interfaces and aspects influence the environmental conditions of the military avionics in the following ways:

The *Environmental Control System* influences the Temperature, Temperature Changes, Pressure, Pressure Changes, Humidity, Contamination, Fungus, Salt Fog, Sand and Dust conditions around military avionics if electrical power is available.

The *Electrical Power Generation and Distribution System* influences the Electrical Supply and EMC conditions for military avionics.
The *Data Links influence also the* EMC.

The *Mechanical Integration* of avionics into the military aircraft influences mainly the Vibration, Acceleration, Shock, Temperature, Temperature Change, Pressure, Pressure Change, Humidity, Contamination, Fungus, Salt Fog, Sand, Dust and EMC conditions of these avionics.

The *Logistical Aspects* like ground support, maintenance, testing, handling, transport and storage have also an effect on environmental conditions like Vibration, Acceleration, Shock, Temperature, Temperature Changes, Pressure, Pressure Changes and Humidity.

5.3 POSSIBLE IMPROVEMENTS OF THE ENVIRONMENTAL CONDITIONS FOR THE MILITARY AVIONICS

In this chapter some examples will be described how the environmental conditions for the military avionics can be improved:

5.3.1 ENVIRONMENTAL CONTROL SYSTEM

Most of the actual produced military aircraft use an Environmental Control System (ECS) based on an engine bleed air, bootstrap, open air cycle and emergency/ground fan air supply concept.

The basics of this technology were developed nearly half a century ago and fit at this time quite well in the overall aircraft concept. Although the efficiency of this concept is very low, requires a lot of engine trust, causing high aerodynamic drag, radar reflections and additional

infrared signatures as well as high temperature / high pressure air leakage risks, it seems to be relatively reliable and light.

This concept provides the military avionics during aircraft ground and main ECS failure conditions with unfiltered and unconditioned aircraft ambient air and during normal ECS operation with unfiltered, partly dehumidified engine or Auxiliary Power Unit (APU) bleed air.

To keep the above mentioned, significant disadvantages as low as possible, these type of ECS were designed to provide just an environment which allows high ruggidised military avionics to survive.

New technologies, in development by EADS Military Aircraft Business Unit in Germany, would allow to design an electrical driven, fuel cooled, closed loop vapour cycle system with much higher efficiency, lower aerodynamic drag, lower signatures, but equivalent reliability and mass.

This concept allows significant improved avionics conditioning, *regarding Temperature, Temperature Changes, Pressure, Pressure Changes, Humidity, Contamination, Fungus, Salt Fog, Sand and Dust,* on ground, in flight and in most of the emergency cases.

5.3.2 ELECTROMAGNETIC COMPATIBILITY (EMC)

A survey of the Electromagnetic Compatibility (EMC) problems to be solved for military systems/equipment is presented in figure 1.

As an absolute preposition the “Internal EMC” has to be guaranteed between all electrical/electronic components installed. Care has to be taken about unwanted radiated and conductive coupling between the different components.

Equipment, which will be integrated into a system, has to fulfil “Intra-System EMC”-requirements. Unwanted emissions have to be limited to tolerable levels. Certain immunities are required to avoid interference caused by other equipment. Radiated coupling paths have to be considered as well as conductive ones. Different types of signals must be taken into consideration starting at short time duration pulses up to continuous wave signals.

Most systems have to operate in a certain electromagnetic field strength environment, which might be generated by the transmitters of other systems or also by external broadcast or radar transmitters. “Inter-System EMC” has to be achieved in such a case. - The environment requirements might reach several 100 V/m up to several kV/m in the case of an aircraft. Simple commercial equipment like e.g. computers have to be protected against an environment up to 3 V/m only. - The electromagnetic environment might affect the electrical components either by penetrating the equipment case or/and by inducing currents on the power and signal lines.

Many equipment have to be protected against lightning strikes. “Direct Effects” caused by direct lightning hits might not be of interest in the most cases. The “Indirect Effects” of lightning, however, have to be considered. Significant currents can be induced in the power and signal lines. In the aircraft e.g. levels up to several kA can have been measured. Similar amplitudes can be expected for equipment installed in buildings.

The “Nuclear Electromagnetic Pulse” (NEMP) has to be considered as a problem, too, for many military systems/equipment. The threat level is defined as 50 kV/m with a rise time of a few ns. The NEMP might affect the electronic components in the equipment via the currents induced in the lines and via the fields penetrating directly through equipment case.

For a selected group of systems/equipment TEMPEST is required. If classified information is handled in a system, it has to be avoided, that the non-encoded electrical signals radiate to the outside.

TREE = “Transient Radiation Effects on Electronic” does not belong directly to the electromagnetic effects. It has, however, to be considered in this context, too. Interference or also damage can be caused in electrical circuits by nuclear radiation directly affecting the semiconductor components.

Comparison Between Military and Commercial Requirements

Table 2 presents a survey about the military and commercial requirements on equipment/systems.

“Internal EMC” between all components installed within an equipment is absolutely required in both cases. There is not a real difference between both sides. Solutions can be realised by e.g. a good EMC-design of the Printed Circuit Boards (PCB`s) and a good de-coupling between the PCB`s in the case (“arrangement, special internal shielding, etc.).

“Intra-System EMC” is not too much different between the commercial and the military side, too. Although different specifications are applied in the commercial and the military world including different procedures and limits, the problems are comparable.

“Inter-System EMC” has to cover generally significantly higher environment requirements in the case of military applications. That means, higher field strength levels have to be considered penetrating equipment cases and higher currents induced on cabling. Additional protection is required.

The problems of “Indirect Effects of Lightning” are similar for military and commercial equipment/systems.

The NEMP is a threat, which is mainly considered for military systems/equipment only. The equipment will be affected via the same coupling paths like considered for the “Inter-System EMC”. High amplitude field pulses might penetrate via the equipment cases. High currents (“damped sinusoidal signals”) might be induced on the lines. Additional protection is required.

TEMPEST is only applicable for selected military systems/equipment. Emissions caused by the non-encoded classified signals have to be controlled very carefully by measures within and outside the equipment. Significant additional protection measures are required.

TREE is also applicable for some selected military systems/equipment only. Some protection measures can

be realised by circuit design, but in general special hardened components should be required.

Survey of Additional Protection Measures Required

Commercial components can be considered to have very similar EMC properties (emissions and susceptibility to interference signals) like the military ones. The only exception is TREE. Commercial components should generally be weaker, because hardening against nuclear radiation requires a component special design. In addition the relevant hardening data are not available for the commercial components.
The consequences for application of commercial components in military equipment/systems are :
If TREE requirements exist, commercial components might cause problems. A lot of statistical test data have to be collected to get sufficient confidence about the hardening level and to demonstrate sufficient protection.
If commercial components shall be applied in all other systems/equipment, there should not be any problem, if the EMC design of the equipment/system follows the usual military guidelines.
Designing the equipment/systems following the commercial rules only, has to be considered to be not sufficient. To cover especially the additional "Inter-System EMC"- and NEMP-aspects, the following additional protection measures are required (figure 3) :

- Improvement of shielding of the equipment case against "Inter-System EMC" – and NEMP – fields to be achieved by :

  - Good electrical sealing between cover and case and different parts of the case
  - Grounding of all mechanical introductions (e.g. also wave guides)directly to equipment case
  - Filtering of all unshielded wires (e.g. power lines) running into the case
  - Avoidance/reduction of openings respectively replacement of large openings by a lot of smaller ones
- Additional interface protection measures against "Inter-System EMC"- and NEMP induced currents
  Filters will help to reduce the CW-signals, suppressor diodes to reduce the NEMP induced signals
- Additional cable shielding against the "Inter-System EMC"- and NEMP induced currents
  A single cable shield, e.g. will reduce the induced currents by a factor of at least 10

TEMPEST might require more intensive protection than "Inter-System EMC" and NEMP. This, however, can also be realised on circuit design-, equipment case- and cabling level and does not exclude the application of commercial components.

5.3.3 VIBRATION

Avionics in actual military aircraft has to cope with a relative high vibration load, which is critical for the sensitive commercial electronic and optical components.

A fixed installation of an avionics box would guarantee stable position of the box, but all occurring vibrations would be transferred directly and unlimited to the sensitive components.

A soft installation on passive vibration dampers, like shock absorbers, would reduce the vibration loads, but with high frequency damping the amplitude of movement due to resonant frequencies would increase.

A combination of passive vibration dampers for high frequencies with an active, adaptive damping for low frequencies showed significant reduction of vibration loads on avionics boxes (see figure 4).

The active and adaptive dampers – e.g. two-axis, electromagnetic linear motors - induce forces with 180° phase-shift (see figure 5) to the vibration loads, which lead to a reduction of the amplitudes.

6. RESUME

The military aircraft would profit from an unlimited application of unscreened, not-ruggid electronic components and design. The environment inside a military aircraft has to be improved to allow reliable use of these components and design. There are technical solutions available to fulfil the environmental requirements of these components and designs. Experimental studies would help to prove this new concept.

7. ABBREVIATIONS

A	Ampere
APU	Auxiliary Power Unit
COTS	Commercial Off The Shelf
CW	
EADS	European Aeronautics, Defense and Space Company
ECS	Environmental Control System
EMC	Electromagnetic Compatibility
g	Gravitational Force [9.81 m/s²]
HW	Hardware
IMA	Integrated Modular Avionics
IT	Information Technology
JTA	Joint Technical Architecture
kA	Kilo-Ampere
kPa	Kilo-Pascal
kV	Kilo-Volt
LCC	Life Cycle Costs
m	Meter
MABU	Military Aircraft Business Unit
NEMP	Nuclear Electromagnetic Pulse
p	Pressure [kPa]
PCB	Printed Circuit Board
SW	Software
T	Temperature [°C]
TREE	Transient Radiation Effects on Electronic
V	Volt

8. LITERATURE

[1] EADS (M) Germany Studies “High Performance Environmental Control and Fuel Systems”, 1996 - 2000

[2] EADS (M) Germany Studies “Adaptive Vibration Damping”, 1997 – 2000

[3] EADS (M) Germany Studies “Advanced Cooling and Thermal Design of Avionics”

[4] EADS (M) Germany / Sextant Avionique Valence Technology Proposal “Environmental Conditions for COTS Components in Modular Avionics (ECOMA)”, December 1999.

9. FIGURES

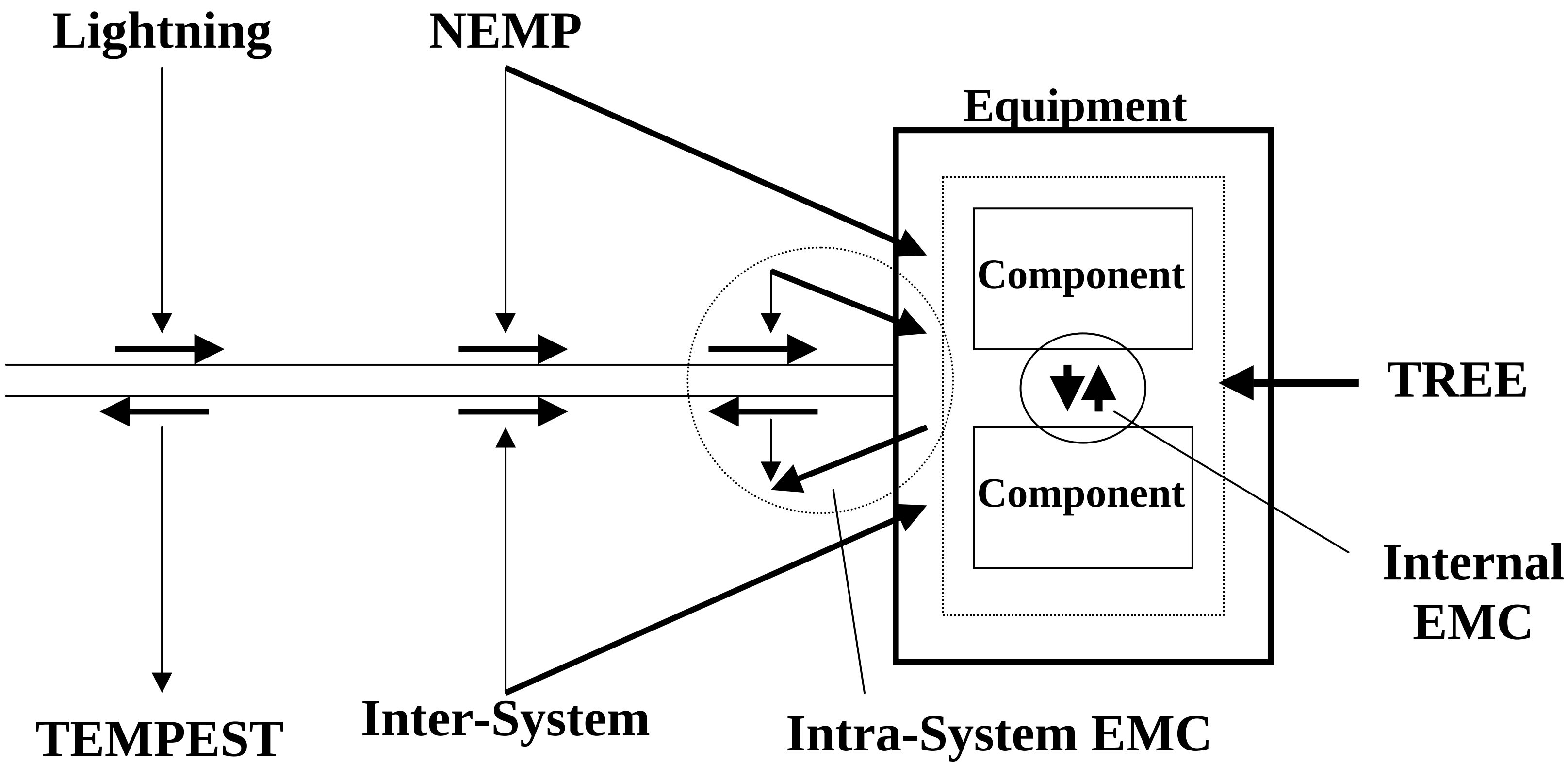


Fig. 1 : Survey of EMC Requirements for Military Equipment/Systems

Field	Requirements		Remarks
	Military Application	Commercial Application	
Internal EMC	Yes	Yes	Absolute preposition; similar problems
Intra-System EMC	Yes	Yes	Other specifications; similar problems
Inter-System EMC	Yes	Yes	In general significantly higher requirements on military side; additional protection required : Case shielding; interface protection : filters, cable shielding)
Lightning Protection (Indirect Effects)	Yes	Yes	Similar problems to be solved
NEMP	Yes	No	Additional requirement, which requires additional protection measures : Case shielding; interfaces : filters, suppressors; cable shielding
TEMPEST	Yes (Selected cases)	No	Additional protection measures required; additional measures for Inter-System EMC and NEMP not sufficient
TREE	Yes (Selected cases)	No	Additional protection measures required; circuit design very often not sufficient; hardened components required

Fig. 2 : Comparison of Requirements for Military and Commercial Application

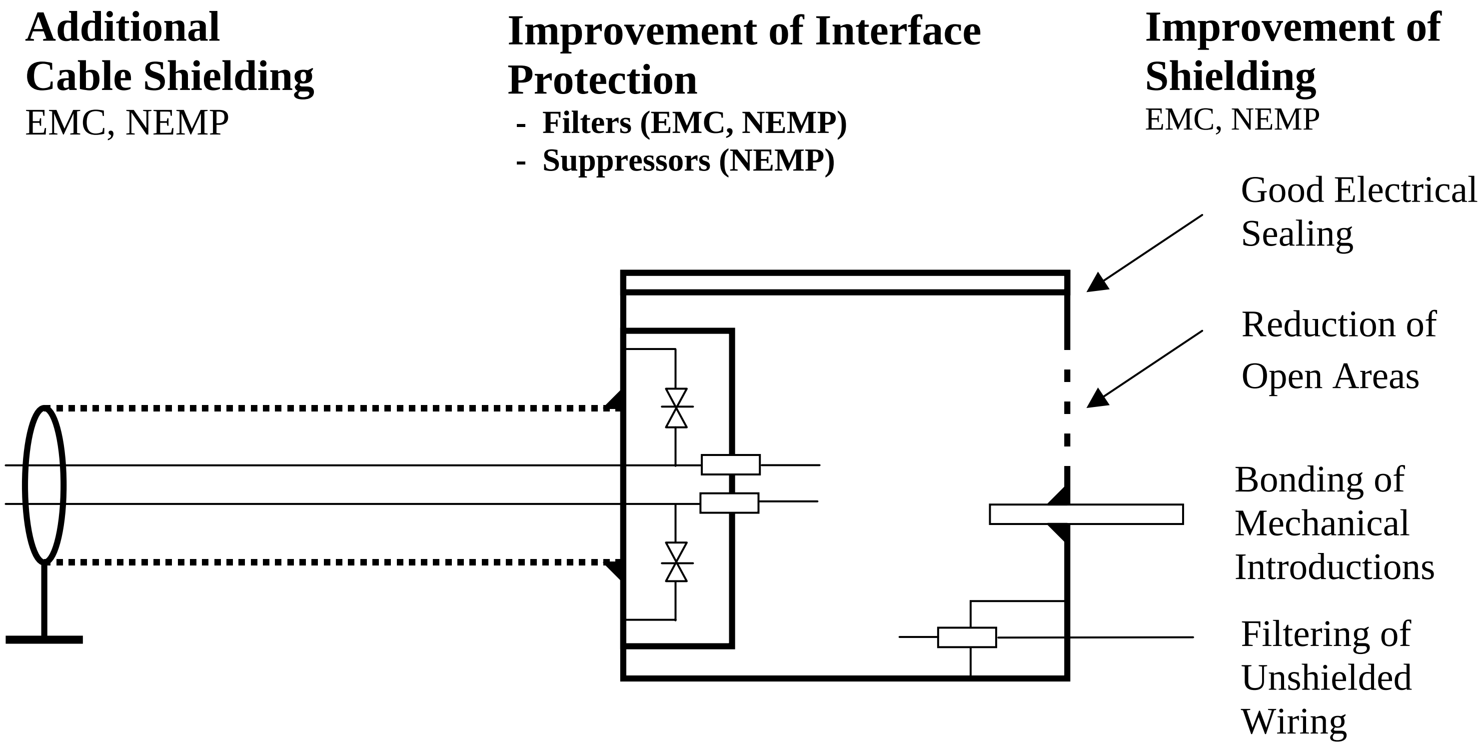
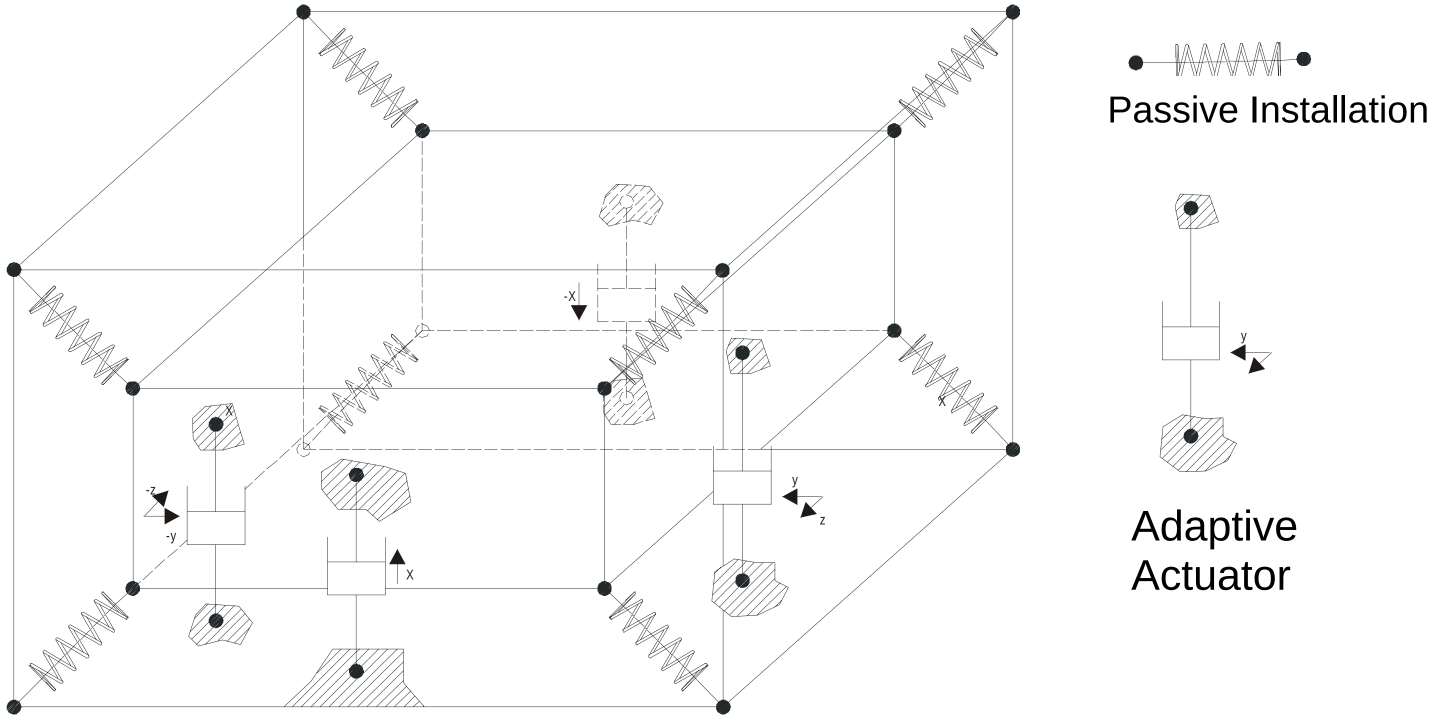


Fig. 3 : Measures to Improve “Inter-System EMC” – and NEMP-Protection

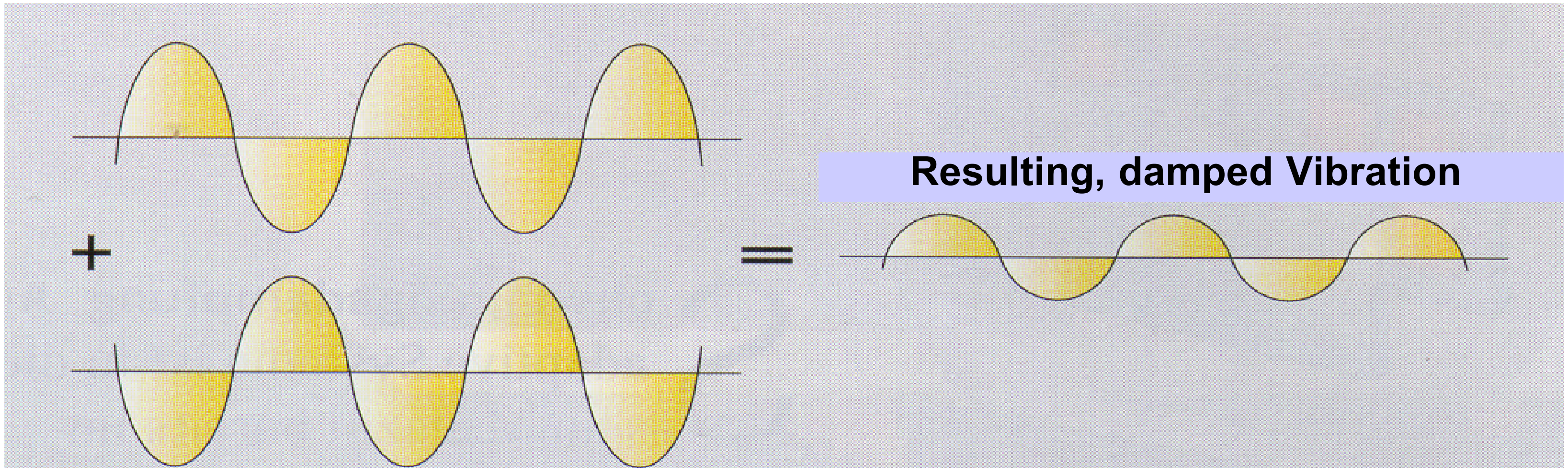
Fig. 4 Active and Adaptive Vibration Dampers:



Schematic of an vibration adaptive Avionics Box Installation

Fig. 5 Vibration Damping - Principal Scheme

Stimulation



Compensation

COTS in our Air Control System

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1 Abstract

A huge international project was launched in 1997 in Hungary: setting up an air control and sovereignty nationwide system based on former Soviet radars and American air sovereignty operations centre (ASOC).

The deadline was extremely short and the available funds low. The main strategy of the project was to use modular elements and commercial components as much as possible.

That is why we decided using PC-s (dual Pentium II class), Windows NT 4.0 operating system and Visual C++ developer system. Some part of hardware were developed using digital signal processors (TEXAS type). Our specialists and American collages worked hard and the American made ASOC centre and the Hungarian information system were used for military service in the fourth quarter of 1998. The system transmitted the radar (military and civil, primer and secondary) information automatically to ASOC in real time.

2 Antecedents of starting the program

In January of 1994 President Clinton suggested building-up a collective regional air control and sovereignty system covering four countries as an integral part of “Partnership for Peace” program on the summit conference of Visegrad countries, in Prague.

In January of 1995 the US Deputy Minister of Defense stated in Trencin (Slovakia) that, his government had accepted building up the system (it means 6.25 million USD for Hungary) after accomplishment of appropriate conditions. The Hungarian government accepted the proposal of USA government (building up ASOC in Hungary) and introduced to the Parliament for approval a resolution.

In September of 1995 The Parliament adopted a resolution (94/1995. OGY), developing of information and control radar system.

The Government of the Hungarian Republic agreed with the necessity of developing of information and control radar system, and assisted that Ministry of Defense to start development and procurement program of modern technical equipment for this action by international application.

The inter-governmental agreement about deployment of ASOC in Hungary (LOA) was signed at the end of 1996.

3 Antecedents of developing of air-defense information system serving Hungarian ASOC

The American-Hungarian professional conference defining connection of information sources to ASOC took place in July of 1997. In third quarter of 1997 establishment of ASOC home conditions could start. It was necessary to develop modern equipment agreed actual demands applying and modifying former developments’ results, regarding actually measuring reports. The document named “Data sheet and basic requirements” was agreed on 30-th July in 1997. The Automation and Radar Department in the Institute of Military Technology prepared the “tactical-technical requirements”, which contained Hungarian requirements. It is the first nation-wide system developed in International Co-operation.

For the proper operation of ASOC there was necessary radar information in plot- or track form to transfer in a defined protocol. There were many tasks in researching and developing (R&D) plan of the Institute of Military Technology falling on developing all system of military radar technology. Institute of Military Technology with civilian companies had many results in these developing tasks, but deploying ASOC system in Hungary had many new aspects of problems in communication protocol interface to the new centre.

3.1 What kinds of tasks had co-operative partners!

3.1.1 Tasks of the USA partner

- Deploying ASOC center (hardware, software) in Veszprém;
- Providing conditions for integrating Hungarian developed systems.

3.1.2 Tasks of the Hungarian partner

- Provide facilities for deployment of ASOC (room, communication, power supply);
- Provide communication systems for ASOC;
- Provide digitizer information sources (radar’, flight plan);
- Getting air picture information by ASOC to users;
- Co-operation in integration of Hungarian developed equipment to ASOC system, together with domestic civilian companies.

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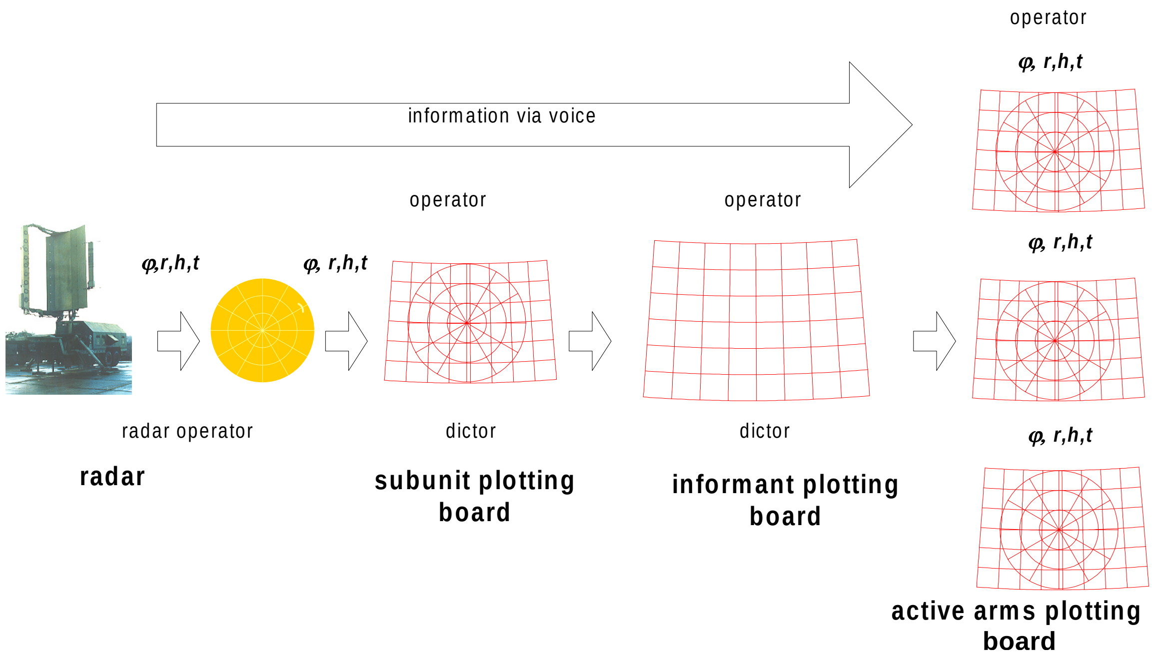
4 The tasks of the ASOC and the connected air traffic control system that was made according to the Hungarian Military Research and Development (R&D)

– Assuring the air sovereignty of the independent Hungarian Republic;
– Gathering information about the objects in the national air space (reconnaissance of the air targets and measure their location with radar's);
– Pre-processing of radar data for transmission (digitalisation, conversion of computer protocols);
– Providing the radar data for processing (sector center functions);
– Analysis and decision preparation (function that helps for the commander at the sector centre and the regional air sovereignty control centre)
– Transmission of target identifier to the active arms (transmission of the commands to the subordinates with displaying on the computer).

4.1 Radar information system before ASOC



Before setting up ASOC the information from radar site to the active arms was translated via voice.
It means that some soldiers dictated the data of flaying objects, others drew them on the plotting board.
The information flow was not too accurate, and was delayed 3 - 6 minute.

4.2 The national system's grouping by the tasks

Providing the different radars as information source

- Civil radars (long-range radar and short-range radar), primary and secondary plot information transmission to the ASOC;
- Military radar’s' primary and secondary plot information transmission to the ASOC;
- Flight data plan (civil and military) transmission to the ASOC.

Accept the air traffic picture made by the ASOC

- Displaying the air position at the active arms;
- Transmission the target identifying directive of the commander's.

Providing the communication with common protocol

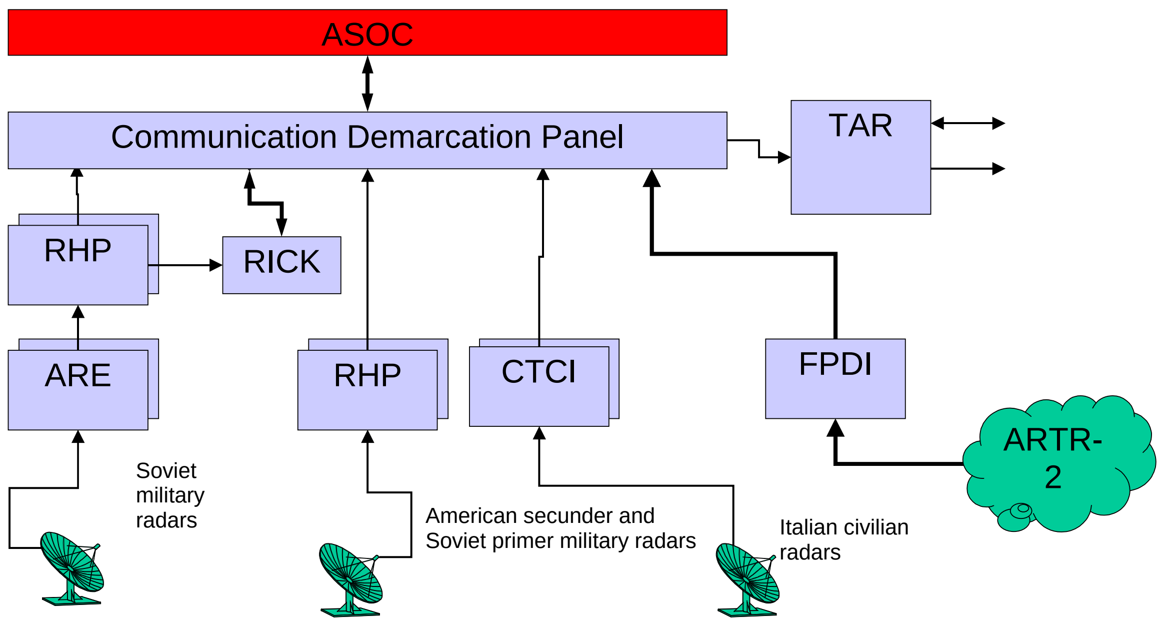
We signed a contract with Hungarian developer enterprises according to the Public Purchase Law.

These were the seven developing tasks:

1. ARE - Automatic Radar Extractor (converter that makes digital sign from the radar video sign)
2. RHP - Radar head processor (tracker instrument)
3. RICK - Radar Information Collecting and Processing Sub-centre
4. FPDI - Flight Plan Data Interface
5. CTCI - Civil Air Traffic Radar Data Control Interface
6. KRI - Communication System Interface
7. TAR - Information Sub-centre

The Hungarian developed air traffic control system connected to ASOC is finished. Under the control of the Ministry of Defense Institute of the Military Technology the Hungarian companies designed, manufactured and measured the necessary hardware and software. The system has been installed at 14 locations according the contracts. Field test started at 1998 August and finished in 1998 October, parallel with the American partner installed the ASOC centre at Veszprém. The final application program's installation and integration to the national air sovereignty control system was carried out in 1998 August. American made ASOC center and the Hungarian information system in use for military service from the fourth quarter of 1998. The system transmitted the radar (military and civil, primer and secondary) information automatically to ASOC in real time.

5 Essential components of the system



5.1 Automatic radar extractor (ARE)

It is a basic part connected to the Hungarian Air Sovereignty Operations Center by means of Radar head processor (RHP). By digitising and transmitting the positions of flying objects in the air it gives the primary military radar information to the ASOC.

5.2 Radar head processor (RHP)

The function of the RHP (tracker computer) acceps secondary radar plots and the primary plots coming from Hughes primary radar extractor. The RHP accepts military radar plots processed by the ARE at air sovereignty control sites where there is no IFF device. The RHP makes tracks from the primary and secondary plots and unifies the tracks belonging to the same target (correlation). The device sends the secondary plot directly to the ASOC. One can make a choice between the transmission primary plots directly to the ASOC or send track transmission to the ”Radar Information Gathering and Processing Subcenter” (RICK).

5.3 Radar Information Gathering and Processing Subcenter (RICK)

It supplies the ASOC system with qualified radar (track) information. It is suited to work out integrated air traffic picture based on RHP track data. Operators are able to provide manual or automatic aircraft’s identification. It supports computer-aided control and identification of civil public flights.

5.4 Flight Planing Data Interface (FPDI)

It provides the flight plan data from “Automated flight planning system” (ARTR-II) to ASOC in a protocol defined in the “ASOC -Interface Design Document” (IDD).

5.5 Civil Air Traffic Radar DATA Control Interface (CTCI)

The CTCIs function is the transmission of three digitised civil radar data to the ASOC. It is also a radar source for ASOC to the creation the continuous real-time air traffic picture.

The second function of the CTCI is the conversion of the radar information from coming the protocol defined MATIAS Interface Control Document (ICD) (ALENIA HDLC protocol, ASTERIX form) to the protocol defined in the “ASOC ICD”.

5.6 Communication System Interface with the Demarcation Panel (KRI)

It provides the communication of the national developed information system, to the data transfer from Hungarian information sources to the demarcation panel. The communication system provides data exchange between the national information sources (Radar Head Processors, civilian radar’s, Radar Information Gathering and Processing Subcenter) and Hungarian ASOC using “Radar Data Multifunction Transmission” (RAMA-2) protocol. It also provides data exchange between foreign information sources (neighbouring ASOCs, NATO centres, military radar information of neighbouring countries) and Hungarian ASOC. It provides the protocol checking of communication and physical connection capability for the information system as well.

5.7 Information Subsystem (TAR)

At the Operations Centre of Air Force Staff the ASOC air traffic picture is distributed from the ASOC output, and is sent target designation to fighters and air defence missile troops’ headquarters by TAR.

6 ASOC tasks

The ASOC is an air-picture displaying system based on the radar data of home digital or digitised 2D or 3D radars. The system-input sources reviewed previously. We had to do the fitting of the data transmission protocol at input sources in all cases. Furthermore the Link-1 connection was important, which through we can be in contact with the airspace control centre of NATO. The ASOC has to take over the former obsolete manual displaying and controlling. The system is capable of providing the airspace control at peacetime, however it gives an opportunity of the later enlargement by defense functions.

7 Strategy of project

When Institute of Military Technology started the project two things were clear: we had extremely short deadline and very low available material founds. To solve the problem we worked very hard. We decided to use all results we reached in the last five years in this field, and built up modular system.. At the end approximately 80% of all systems was built up in commercial components. We used PC-s (dual pentium II 266Mhz), Windows NT 4.0 operating system and Visual C++ developer system.

8 Operating experience

The nation-wide system has been working for 2 years. The system consists of more than 20 PC-s, and operates for 24 hours/day.

There were 19 hardware and 8 software failure in this year.

Most of the problems were caused by the uninterruptible power source.

Least of the problems were caused by the monitors. Monitor problem occurred only once in two years.

The ASOC system with the domestic developed input and output equipment change the obsolete airspace control system. Nowadays it is

impossible to control the huge amount of aircrafts crossing our airspace.

The problems have been solved by the real time digital equipment. The reliability of the system is determined by reliability of our radars and communication lines, therefore we have to improve the system at these fields.

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Risk-Based COTS Systems Engineering Assessment Model: A Systems Engineering Management Tool and Assessment Methodology to Cope with the Risk of Commercial Off-the-Shelf (COTS) Technology Insertion During the System Life Cycle

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1.0 INTRODUCTION

Due to the rising costs of today's weapon systems, the U.S. Department of Defense (DOD) continues to implement strategies to reform its acquisition and procurement process. One such strategy seeks to reduce the cost of developing systems by purchasing commercial off-the-shelf (COTS) technology. The COTS technology ranges from components used to build a particular weapon system to functional pieces of gear used to support the weapon system, i.e., support equipment. The COTS technology may be instituted at the inception of the weapon system design or it may be inserted into the support of the weapon system at any point during its life cycle. The COTS technology is intended to reduce weapon system life-cycle costs by minimizing the expense of system design and testing.

While using COTS technology is beneficial to the DOD, several factors must be weighed before such technologies can be introduced effectively. Above all, the typical systems engineering thought process must be adjusted to incorporate the potential risks of COTS technology. One of the most significant risks involves parts obsolescence. Systems engineers must decide how and when to use rapidly changing COTS technology to keep pace with the commercial technology market. Technology manufacturers regularly develop new versions of electronics and software and new designs of mechanical parts. These rapid changes lead to technology "outpacing" fielded military systems, which often have long life spans and require legacy parts support. Previously, as one of the most influential players in the development of technologies such as electronics, the DOD often "drove" technology development to fulfill its needs. Now, increasing demands for electronic technologies from all sectors of the market (e.g., industrial, professional, personal, and government) have lessened the DOD's influence on the pace of technology development. And, while the DOD's desire to field new and innovative technologies has increased, acquisition budgets have actually decreased. As a result, the DOD finds it more difficult to drive major price efficiencies than in the past. Because the commercial industry currently views the DOD as a different kind of player in the technology market—one with more stringent requirements than other customers—the DOD no longer can easily influence technology suppliers to design, test, and support their products in the manner prescribed by the DOD. In short, technology suppliers are less willing to guarantee the configuration design stability and logistics support required by DOD systems engineers to ensure that a weapon system will be adequately supported throughout its life cycle. This diminished technology support, if not managed properly, can lead to parts obsolescence, which in turn can lead to increased life-cycle costs for a weapon system, as well as diminished mission readiness.

For example, there is an inherent risk if the DOD procures COTS equipment for a specific weapon system and the technology manufacturer ceases to provide replacement parts because technology has advanced since that equipment was fielded. In the best-case scenario, the manufacturer designed its equipment using open architecture and either the new, updated technology parts can directly replace the old parts in the fielded equipment or they can be integrated using a manufacturer-supplied interface. In the worst-case scenario, replacement parts are not available because the manufacturer has either gone out of business or did not plan to supply upgraded or original parts to the DOD over the lifetime of the weapon system. In either case, the DOD will have to cover the risk to mission readiness, as well as the cost of replacing obsolete parts or even redesigning/modifying the equipment to make it compatible with the new technology parts.

Additionally, one of the prevailing and flawed opinions in applying COTS technology to DOD weapon systems is that "if the technology exists in the commercial marketplace, it already must be appropriate for use in

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the military and, therefore, validation and testing of the technology are unnecessary requirements." This is an unacceptable risk because every piece of equipment must meet an acceptable set of requirements relative to the DOD operational environment for which it is intended. The military mission and operating environment can be distinctly different than those of industry, and technologies must be tested and validated to withstand factors such as extreme shock, vibration, and corrosion. The appropriate level of testing and validation must be determined based on the type of technology and how it will be fielded. Ideally, a COTS technology may be subject to a reduced level of DOD testing based on established commercial testing data. If this is the case, the DOD will realize a cost savings.

When specifying COTS technology, parts obsolescence, validation, and testing risks must be effectively balanced with system performance, life-cycle costs (affordability), and overall supportability. One management tool and methodology that helps systems engineers identify COTS technology risk factors was developed by the Naval Air Warfare Center Aircraft Division, Lakehurst, New Jersey (NAVAIRWARCENACDIVLKE) under the Naval Air Systems Command. The Risk-Based COTS Systems Engineering Assessment Model is a tool that addresses the need for better systems engineering integrated decision-making. The model can improve the military systems engineering management decision framework so that COTS technology integration is considered as an alternative to "cradle-to-grave" development of DOD weapon systems. Ultimately, the model reduces risk and uncertainty in the engineering of defense systems that use COTS technology.

2.0 ACQUISITION REFORM INITIATIVE

Several key measures facilitate the accelerated introduction of commercial technologies into DOD weapon systems.

2.1 COTS Technology

Various DOD directives have led to the current focus on procuring COTS technology. For example, DOD Directive 5000.1 prescribes a systems engineering approach throughout the entire life cycle of a system and categorizes the four basic types of acquisition in order of preference:

a. Modification of existing system
b. Procurement of a COTS item
c. Procurement of a nondevelopmental item
d. Development of a new system.

The DOD's Acquisition Reform Initiative is a mandated effort to reduce the cost of systems acquisition through measures such as COTS technology procurement. The benefits of DOD acquisition of COTS technology can be significant, especially with respect to eliminating developmental costs, but the appropriate risk factors must be explored for each unique case.

2.2 *Open System Architecture*

A major contributor to the success of COTS-based technology solutions is an open architecture design. DOD Directive 5000.2-R strongly encourages the design of open architecture for DOD-developed systems in order to ensure flexibility and scalability and to facilitate the insertion and integration of technology. In many cases, industry also has embraced open architecture in order to promote supportability, interoperability, and scalability as means of reducing production costs and gaining a competitive advantage. Manufacturers who employ the principles of open architecture represent reduced risk to the DOD when procuring COTS technology.

Some industry standards promote open architecture. For example, small components such as valves often are designed using open architecture standards to ensure that they can be applied to and interchanged with a wide range of systems. Unfortunately, other types of mechanical components, such as pumps, may not be adapted as easily between systems. For example, if a manufacturer develops a system that includes a unique component A, which for some reason becomes unavailable as a replacement part, then a new component B, possibly from a different manufacturer, must be integrated. If the system was not designed with open standards to accommodate a different component, it will require redesign work and/or a new interface for component B to be retrofitted into the system.

The interchangeability of critical parts is therefore an important factor when determining the risk of parts obsolescence and the supportability of a COTS system. The COTS systems, which are designed with open architecture and open standards, yield reduced risk and life-cycle costs.

3.0 SYSTEMS ENGINEERING

The impetus for greater application of COTS technology creates a new systems engineering challenge—to cost-effectively assess and integrate commercial technologies prone to continuous change. Predicting these changes and ensuring minimal risk can be a difficult task. The overall goal is to meet mission requirements while ensuring cost, schedule, and performance throughout the weapon system life cycle. This goal can be compromised by poorly estimating the risks involved with COTS technology insertion.

To compensate for rapid COTS technology changes, systems engineers must identify strategies and a common framework that will aid in projecting and

mitigating these issues early in the weapon system development cycle. By addressing market (i.e., technology manufacturer) concerns early, the volatility of COTS technology insertion can be controlled and potential problems, such as parts obsolescence, can be minimized.

The first step toward meeting this objective is to assess the viability of the commercial technology in the context of performance, complexity, criticality, supportability, and life-cycle cost factors. The Risk-Based COTS Systems Engineering Assessment Model is a common framework that allows systems engineers to meet the goals and minimize the risks of COTS technology insertion at any phase during the weapon system's acquisition life cycle. The model can be used as a life-cycle risk assessment methodology to determine lifelong buys versus COTS technology insertion, to identify open architecture and open standards, to assess supportability, to design processes, and to select materials. It is a life-cycle management tool for dealing with the risk of obsolescence and overcoming the barriers to using COTS technology in defense systems. An innovative aspect of the model is the use of a cube diagram to represent the relative risks of different COTS alternatives (reference Section 4.3).

4.0 ASSESSMENT AND VALIDATION MODEL

The Risk-Based COTS Systems Engineering Assessment Model was developed to ensure that systems engineers can select the most cost-effective COTS equipment based on its affordability, reliability, mission requirements, and ability to accommodate replacement and/or future modification. A risk-based approach to decision-making, the model enables systems engineers to apply a variety of risk perspectives while using information from technology market analyses. For example, market analysis information can be used to assess whether a manufacturer uses open architecture or is likely to have the "staying power" to provide long-term support. The model also assists with determining the level of validation and testing required to further reduce the risk of using COTS equipment. The model allows competing COTS equipment to be judged fairly in order to identify which manufacturer allows the DOD to take the greatest advantage of using COTS equipment (e.g., the manufacturer whose technology meets the mission requirements, uses open architecture, and provides verifiable data to limit the amount of DOD testing and validation required).

For instance, the model can assist in recognizing the worst-case parts obsolescence scenario—selecting equipment that has a high perceived risk of not functioning during a conflict as a result of the unavailability of parts or the incompatibility of newly upgraded parts with fielded equipment. The best-case scenario is one in which the equipment meets the mission by using readily available and supportable COTS parts and open architecture. In this case, components can be replaced to compensate for, as well as to take advantage of, advances in technology.

The model is intended to be a tool that can be applied throughout the lifetime of a system. Ideally, the model should be used to perform a baseline analysis when system development commences. The analysis can be revised and adjusted later during each major milestone or acquisition phase to account for new requirements or factors that were not originally relevant or defined. If a weapon system has progressed beyond the development stage, the model can still be applied at any time to assist with COTS technology decision-making. The model functions best when it is combined with a suitable life-cycle cost model.

Overall, the model works iteratively to define requirements, insert market knowledge, and identify risk. Each COTS alternative is applied to the model. If alternative 1 yields unacceptable risk, consecutive alternatives are evaluated until the alternative(s) with the least risk is identified. If all of the available alternatives have unacceptable risk, either the mission requirements must be reevaluated or other suitable alternatives must be found through additional market analysis. The model defines risk as a function of mission criticality, technical complexity, and life-cycle costs. For example, the risk of parts obsolescence is translated as a risk to the mission and as a potential impact on life-cycle costs. Furthermore, unless the item has been designed using open architecture, the risk of parts obsolescence is evaluated according to the technical complexity of the COTS technology—the more technically complex the technology, the greater the perceived risk of parts obsolescence.

The goal of engineering suitable COTS equipment solutions can be reached by employing the model in accordance with the following steps:

a. Perform market surveillance and construct an ongoing commodity strategy for future needs.

b. **Logical Solution**—Perform an operational requirements analysis (e.g., define mission, performance, functionality, reliability, maintainability, supportability, and environmental requirements).

c. **Physical Solution**—Translate requirements into COTS solutions by applying market analysis.

d. **Alternatives Risk Assessment (a central element of the model)—**Perform an alternatives and risk assessment

- Evaluate the ability of each alternative to meet the defined requirements.
- Determine the requirements thresholds.
- Determine the requirements validation and testing required.
- Determine supportability plans and evaluate open architecture design.
- Determine risk factors to performance, cost, and schedule.
- Determine the estimated life-cycle cost.

e. **Mitigation of Risk—**Perform verification and qualification

- Analyze commercial data and past performance
- Determine required testing and validation of sample equipment.

Figure 1 summarizes these steps and shows how the model fits into the traditional systems requirements decision-making process.

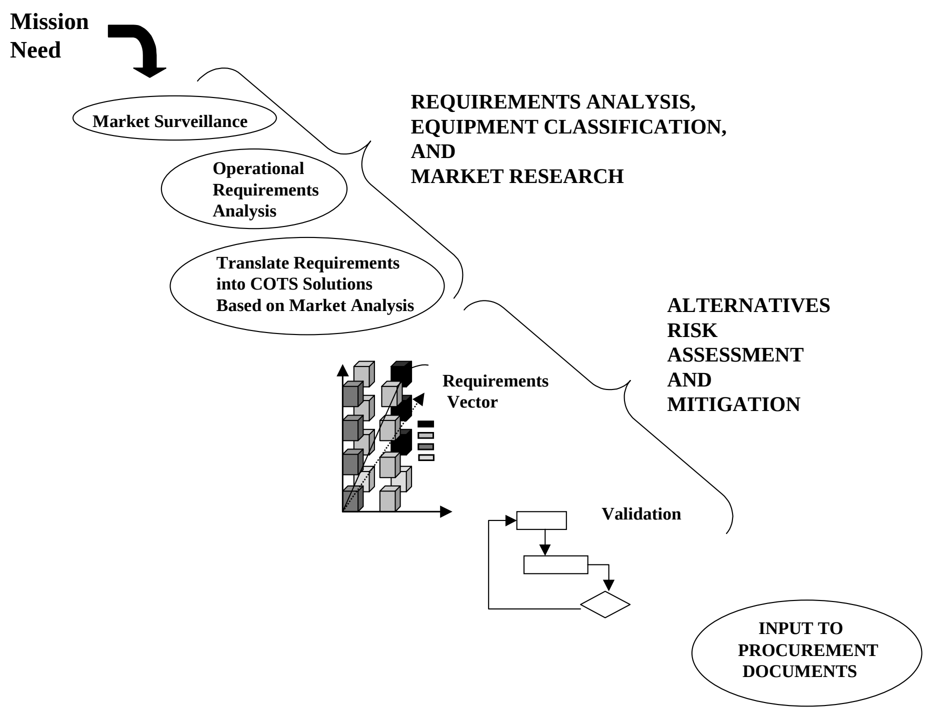

Figure 1. Summary

Figure 2 represents the iterative process that occurs after the need for a piece of equipment is defined. Blocks 1, 2, and 3 relate to defining requirements, determining market-based COTS solutions, and assessing each COTS alternative. If none of the COTS alternatives represents acceptable risk, the mission requirements must be reevaluated or a decision must be made to develop the equipment in-house (DOD design and develop) rather than procuring COTS equipment. If one or more COTS alternatives represent acceptable risk, a procurement strategy for COTS equipment should be formulated based on the best alternative.

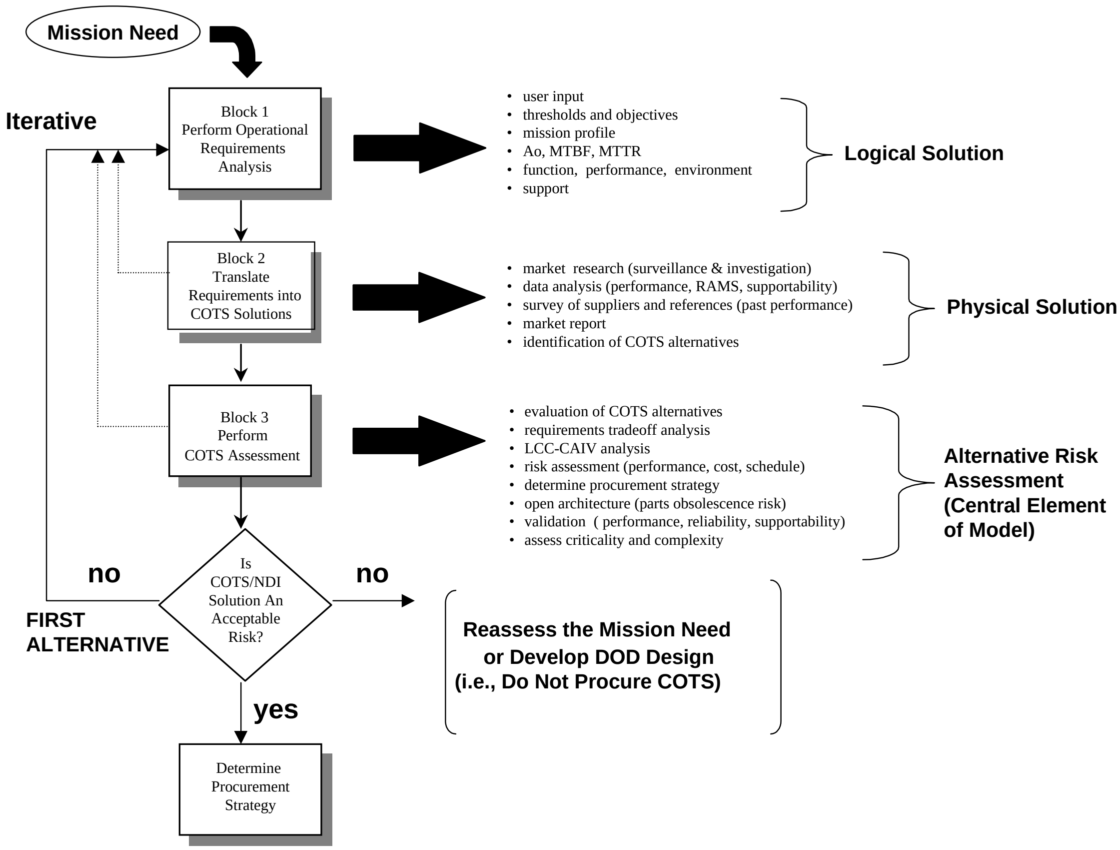

Figure 2. Iterative Decision Analysis Process

4.1 The Logical Solution

Block 1 of Figure 2, Perform Operational Requirements Analysis, includes the following substeps:

- Compile user input (e.g., feedback from shipboard/flight line personnel).
- Define the mission profile and mission analysis.
- Define thresholds and objectives.
- Perform a functional analysis.
- Perform a supportability analysis.
- Define performance attributes.
- Determine operational availability (Ao), allowable mean time between failures (MTBF), and mean time to repair (MTTR).
- Define the operational environment requirements (e.g., shock, vibration, weather).
- Determine estimated inventory and allocation allowances.

4.2 The Physical Solution

Block 2 of Figure 2, entitled Translate Requirements into COTS Solutions, includes substeps such as performing market research, analyzing market data, and surveying COTS equipment suppliers. Market research builds on continuous market surveillance to develop a commodity strategy and market investigation. The market investigation should yield COTS alternatives that meet the requirements of the logical solution (defined above). A typical market investigation results in an evaluation and report of the following items:

- Summary of market surveillance information
- List of potential sources
- Survey of potential supply sources (e.g., Internet search, journals, *Commerce Business Daily* contract awards, etc.)
- Input from references (i.e., current users of similar equipment)
- Compilation of equipment capabilities (e.g., performance, supportability, history, etc.).

Table 1 lists some factors that should be considered when reviewing open standards, equipment profiles, and their related technologies and products.

Table 1. Market and Technology Supplier Analysis

(Source: Next Generation Computer Resources (NGCR), Document No. AST002, Version 0.04 of the NGCR Supportability Guide, draft dated 27 April 1995, SPAWAR.)

Maturity of the Standards, Technologies, and Products	➢ Is the technology mature? ➢ Are the products fairly stable? ➢ What is the product "upgrade" cycle time? ➢ When is the next planned update? ➢ Are the products being refined or significantly changed during each cycle?
Multiple Product Sources	➢ Are there multiple sources for products that meet the requirements analysis? ➢ Are these products interoperable? ➢ Do these products merely accept data from each other or do they meet the same performance levels (interchangeability)?
Market Acceptance	➢ Is the standard, profile, or product well accepted in the commercial marketplace? ➢ What are the respective vendors' market shares? ➢ Are the commercial markets large enough to imply that long-term support and upgrade of the product will be an investment borne by the commercial market sector or will the DOD become the only user in a relatively short time?
Product Line Families	➢ Do product families exist? ➢ Will usage of a given product tie the DOD to a product family? ➢ Will such a relationship be expensive? ➢ Is the existing support structure well-suited to the operational requirements? ➢ Will supplements, upgrades, or replacements be necessary (e.g., technical data, training, repair, spare parts support, etc.)? ➢ Should the product family or the individual product alone be approved for use?
Test and Evaluation	➢ What ongoing test and evaluation parameters are employed by the vendor? ➢ How would the DOD test this product? ➢ Will the existing test capability and data meet the DOD's needs? ➢ Will test data from families of products be applicable? ➢ How much will required testing cost?
Technical Data	➢ Are the technical data provided by the various vendors sufficient? ➢ Are the data useable? If no, what problems can be foreseen? ➢ What workarounds are necessary? ➢ What additional data are necessary?
Configuration Management (CM)	➢ Is the contractor's CM program adequate to meet weapon system program office needs? ➢ Can the contractor's CM program be modified or supplemented if necessary? By the contractor or the government? ➢ What will the cost be and who will bear this cost?
Availability	➢ What is the operational availability (Ao)? ➢ What is the inherent availability? ➢ What is the mean time to repair (MTTR)? ➢ What is the mean time between failures (MTBF)?
Performance Monitoring and Built-in Test	➢ Does the product have a built-in self-test? ➢ Is the self-test capability sufficient from a systems-level viewpoint? ➢ Will the self-test be difficult to reintegrate when updates occur (e.g., engineering, training, configuration status and management, supply support)?
Quality Assurance	➢ Does the vendor provide a warranty and what is included in the warranty? ➢ Is the vendor ISO 9000 compliant? ➢ What other quality assurance measures does the vendor provide?

4.3 The Alternatives Risk Assessment

Block 3 of Figure 2, entitled Perform COTS Assessment, includes the following substeps:

- Classify each COTS alternative based on criticality and complexity. (Since each alternative is a possible solution for the same need, it is expected that the criticality will remain the same for each alternative; however, the complexity may vary with each alternative.).
- Evaluate the anticipated life-cycle cost analysis for each COTS alternative.
- Assess each COTS alternative based on:
  - ➢ Ability to meet threshold and objective requirements
  - ➢ Supportability (e.g., open architecture design reduces parts obsolescence)
  - ➢ Life-cycle cost.
  - Assess the risk of each COTS alternative:
  - ➢ Technical risk = *f* (mission criticality, technical complexity, life-cycle cost [LCC])

To perform the alternatives risk assessment—the central element of the model—the technical complexity and criticality of each COTS alternative must be established. The alternatives are categorized using the following definitions:

- Complexity
  - ➢ Non-Complex – A nonrepairable piece of equipment (i.e., consumable) or a repairable piece of equipment with no repairable subassemblies.
  - ➢ Complex I – Equipment with one or more repairable subassembly.
  - ➢ Complex II – Equipment that meets the definition of Complex I and is self-powered (i.e., engine, hydraulic, electric, or pneumatic-powered).
  - ➢ Complex III – Equipment that meets the definition of Complex II and has feedback control (i.e., does not have data acquisition).

- Criticality
  - ➢ Non-Critical – Requires scheduled and/or unscheduled maintenance, but is not considered mission- or safety-critical.
  - ➢ Mission Critical – Failure of this equipment could damage the weapon system or degrade the weapon system mission.
  - ➢ Safety Critical – Failure of this equipment could harm personnel.

Next, the equipment alternatives should be assessed to determine approximate life-cycle costs. At this point, the alternatives can be positioned on a three-dimensional cube that forms the basis of the Risk-Based COTS Systems Engineering Assessment Model (refer to Figure 3).

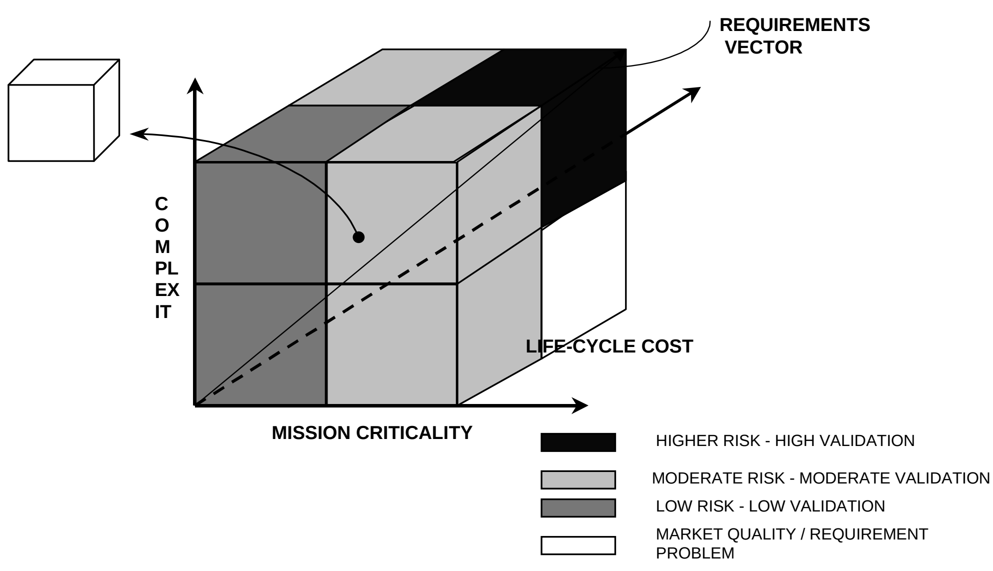

Figure 3. Degree of Validation as a Function of Technical Risk
Risk = ***f*** (mission criticality, technical complexity, LCC)

This cube allows the systems engineer to determine the degree of validation required as a function of technical risk. Risk is a function of three factors: criticality, complexity, and life-cycle cost. The cube enables systems engineers to visualize alternatives as a composite of their contribution to the mission versus their ease of repair and supportability versus cost. The y-axis of the cube represents increasing complexity,

and the x-axis represents increasing criticality. The z-axis represents increasing life-cycle costs. Each available COTS alternative should be positioned in a sector of the cube. The cube is color-coded to indicate which sectors represent low, moderate and high risk, which correspond to low, moderate, and high requirements for equipment validation. For example, the color-coded location of the sector for those alternatives that are noncritical and noncomplex with a low life-cycle cost indicates low risk and, therefore, relatively low requirements for equipment validation. The color-coded location of the sector for those alternatives that are highly mission- or safety-critical and highly complex with a high life-cycle cost indicates high risk and relatively high validation requirements. The model also indicates potential acquisition problems, such as alternatives that fall into the sector for low complexity and low criticality with high life-cycle costs. Such sectors are color-coded to indicate either a problem with the availability of an appropriate alternative in the marketplace or that the requirements have been poorly defined.

Figure 4 illustrates a fragmented version of the cube that enables better visualization of each sector. This model expands the cube to include sectors based on all four definitions of complexity.

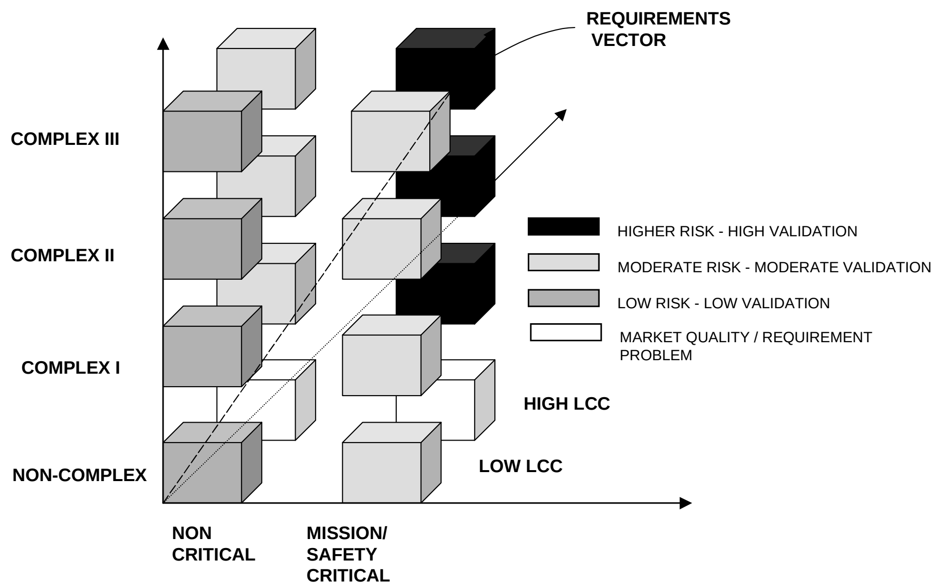

Figure 4. Degree of Validation as a Function of Technical Risk - Fragmented Cube
Risk = ***f*** (mission criticality, technical complexity, LCC)

As an example of the different components and support equipment that comprise a weapon system, Figure 5 is a version of the fragmented cube with various pieces of aircraft support equipment labeled on the appropriate sectors. By using the fragmented cube to visualize an entire weapon system, systems engineers can select the areas that may be most appropriate for COTS equipment to be inserted and/or ensure that the appropriate level of validation occurs when evaluating COTS equipment based on risk.

Acronym List

SETS-standard engine test system
HCTS-hydraulic component test stand
JASU-jet air start unit
ADTS-air data test set
MEPP-mobile electric power plant
AGTS-aircraft generator test stand
NDI-nondestructive inspection equipment
O_2 GEN-oxygen generating cart
MAINT PLAT-maintenance platform

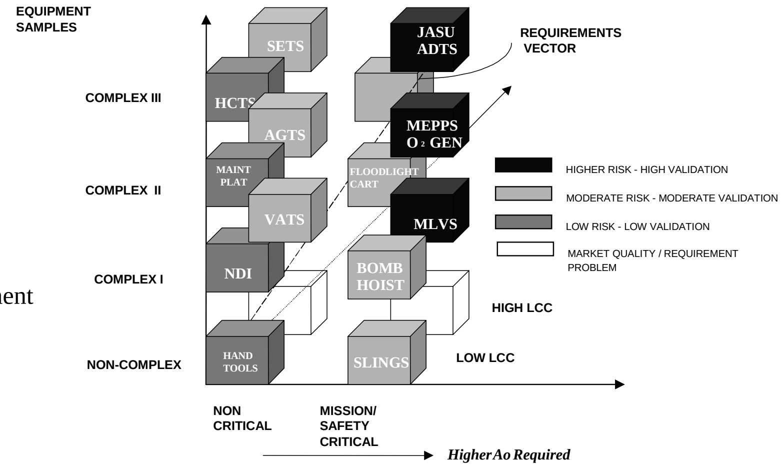

Figure 5. Weapon System Example of Fragmented Cube
Risk = ***f*** (mission criticality, technical complexity, LCC

4.4 The Mitigation of Risk

When assessing COTS alternatives, it is necessary to determine what, if any, performance and environmental degree of reliability and maintainability (R&M) validation and testing are required. Figure 6 shows an example of a logical flow diagram validation strategy for COTS equipment R&M validation decision factors based on criticality and complexity. The goal is not to "overtest" or "undertest" COTS equipment.

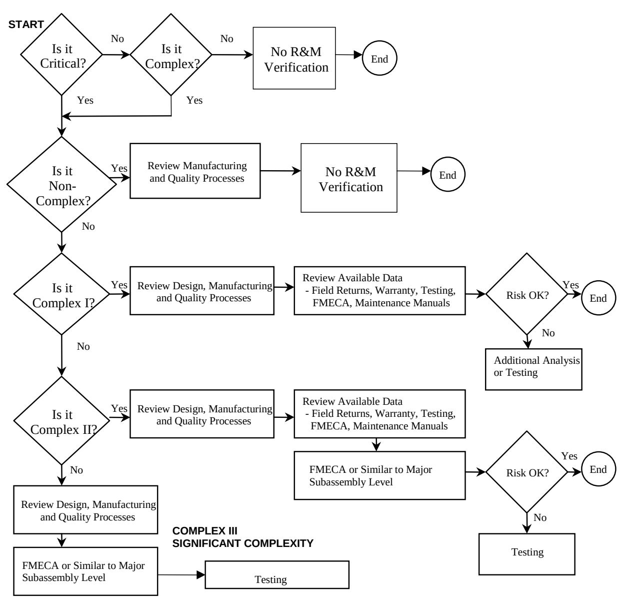

Figure 6. Reliability and Maintainability Validation Strategies
(*Source: Janet L. French, NAVAIR Reliability Engineering)*

Tables 2 and 3 represent the types of commercial equivalent data and equivalent testing that can be used to assess the degree of additional testing or validation that may be required. In each case, a lack of commercial data or testing protocols increases risk and may necessitate full or partial DOD testing of the equipment. The goal is to take advantage of existing data and testing to reduce the cost of required R&M testing and validation.

Table 2. R&M Validation
Analysis and Data

Analysis Data Required	Critical & Noncomplex	Complex & Not Critical	Electrical/ Electronic Critical & Complex	Mechanical Critical & Complex	Critical & Complex II	Critical & Complex III
R design practices			✓		✓	✓
R prediction			✓		✓	✓
FMECA			✓	✓	✓	✓
M design practices*			✓		✓	✓
M prediction*			✓		✓	✓

*Maintenance philosophy-dependent

Table 3. R&M Validation
Testing

Testing	Critical & Noncomplex	Complex & Not Critical	Electrical/ Electronic Critical & Complex	Mechanical Critical & Complex	Critical & Complex II	Critical & Complex III
ESS			✓		✓	✓
RQT			✓	✓	✓	✓
RD/GT*					As required*	As required*
M demo**			✓	✓	✓	✓

*For systems where several COTS items are integrated.
**Maintenance philosophy dependent

Legend:

R—reliability
FMECA—failure modes effects and criticality analysis
M—maintainability
ESS—environmental stress screening
RQT—reliability qualification testing
RD/GT—reliability development/growth testing

When conducting an R&M risk assessment, the following pertinent questions should be included:

- Has the vendor provided sufficient information to indicate that R&M requirements can be achieved?
- Are there any new or untried technologies or components within the product that have a limited or nonexistent record of reliability performance?
- What techniques does the vendor use to maintain or improve product reliability and quality?
- How does the vendor select subvendors (e.g., qualified lists, lowest cost, etc.)?
- Does the vendor verify component quality?
- Are there any frequent failures that could impact safety or the mission?
- Are there any frequent failures of high-cost items? Hard-to-replace items? Hard-to-maintain items?
- Is the commercial use environment sufficiently similar that the data are indicative of the types of failures likely in the DOD environment?
- Are there any test data and are they verifiable?

Figure 7 illustrates the decision factors related to COTS equipment supportability validation requirements. This analysis shows that open architecture is beneficial to COTS equipment alternatives.

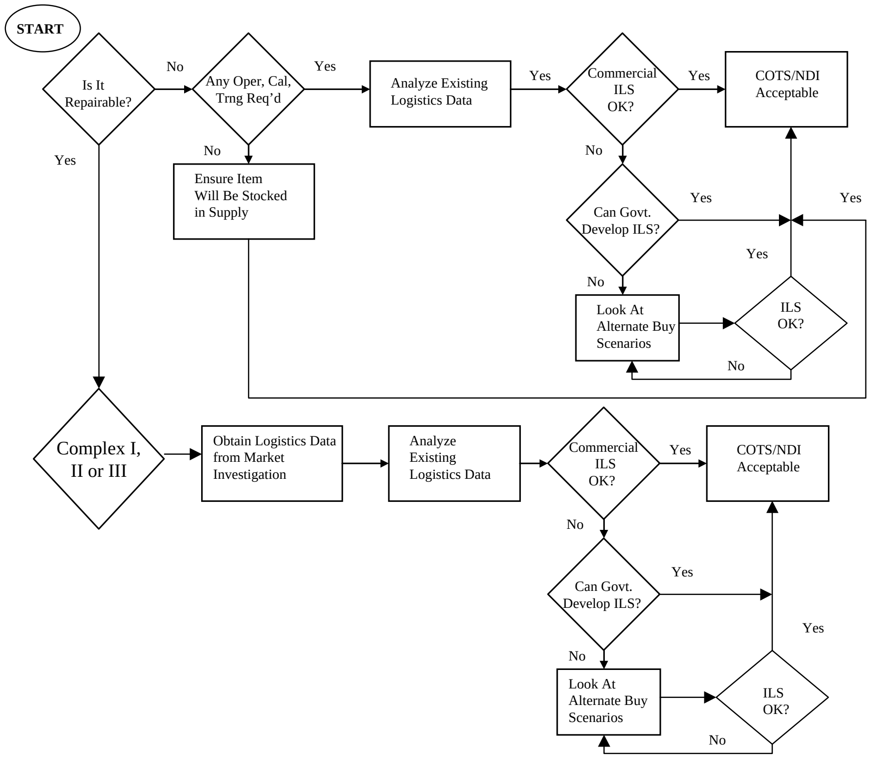

Figure 7. Supportability Validation Strategies
Logistics Validation
(Source: Edward F. Waraksa, NAVAIR Logistics Management)

Various types of commercial data may be available to perform R&M and supportability analyses of COTS alternatives. Table 4 illustrates several key sources.

Similar validation flow diagram strategies must be developed to address performance as well as environmental requirements.

Table 4. Commercial Data Sources Related to Validation of R&M and Supportability

Historical R&M Experience	• Estimates of expected reliability • Warranty provisions • Customer satisfaction indices
Internal Manufacturing Quality Procedures	• Production controls • ISO 9000 or similar techniques • Testing procedures
Vendor or Component Selection Policy	• Parts control methods • Quality control techniques • Testing procedures • Environmental stress screening
Design Approach	• Environmental approach • Part derating procedures • Fault tolerance features • Ruggedization concepts • Built-in test features • Ease-of-maintenance features

In summary (refer to Figure 1), the Risk-Based COTS Systems Engineering Assessment Model components can be summarized as the following steps - beginning with the mission need, requirements definition and analysis, market research and identification of COTS solutions, use of the fragmented cube and validation flow charts to assess and reduce risk and, finally, providing input for procurement.

5.0 CONCLUSIONS

In summary, the DOD's increasing reliance on advanced technology, such as electronics, dramatically increases the cost of developing weapon systems, as well as the operational cost of redesigning and upgrading these systems as technologies change. To avoid some of these costs, the DOD must take advantage of industry's ability to bring components and systems to market faster than the DOD can develop them. It is important to weigh the risks of COTS technology over the life cycle of the system and insert these commercial technologies where the risks and benefits are prudent. Without proper management, COTS can be a drawback as a result of poorly defined risk—such as the likelihood of performance and cost risks as well as parts obsolescence in the field. The Risk-Based COTS Systems Engineering Assessment Model serves to define such risks and helps systems engineers make informed decisions.

The Risk-Based COTS Systems Engineering Assessment Model provides a common framework for making COTS technology decisions by assessing the relative risk of each COTS alternative. It also provides assistance in determining the appropriate degree of validation required to verify that a COTS alternative can be transferred to the military environment.

To take advantage of COTS technology and better apply the model, the systems engineering community needs the following:

- Better requirements analysis tools that incorporate risk.
- Better industry information (i.e., life-cycle cost data, time until market release/update data, and supportability data.
- Better market surveillance and segmentation (i.e., systems engineers must become cognizant of market factors and sectors for different technologies).
- Better system of open architecture standards in the marketplace (e.g., electronic and mechanical standards that incorporate open architecture).
- Better assessment tools that are standardized and used by all NATO military organizations.

The Risk-Based COTS Systems Engineering Assessment Model offers important benefits and insight to the overall weapon system acquisition management process. It should be noted that significant work must still be invested to make the application more efficient, such as refining the functional interrelationship between complexity, mission, and cost. The need to further optimize the model is necessary if better fidelity is desired. Integrating and automating the complexity criteria with mission criticality and cost analysis is the ideal formula for concurrent engineering analysis, which when applied improves the chances of selecting effective commercial equipment. Automating and combining the model can significantly improve implementation and accelerate the transfer of commercial technology in a synergistic manner.

The authors would like to acknowledge Janet L. French and Edward F. Waraksa for their contributions to this paper.

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Methodological Guide to ASIC Design with Durability Management "COCISPER: *Co*nception *C*ircuits *I*ntégrés *S*pécifiques et *Per*ennité"

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SUMMARY

The military sector is characterised by specific aspects such as small series, high reliability, long life-cycle products. In this context, the DGA wished to set up means to develop specific integrated circuits for the durability of electronic systems.

Thus, in 1995, a first COCISPER contract has been awarded to a Consortium fully representative of the industry in France.

It is aimed to establish a methodology guide for designing ASIC taking into account the needs for system durability. Therefore, it defines an industrial standard following the withdrawal of mil-spec ones.

The guide produced within this project specifies the general development plan of numeric integrated circuits at the ASIC design process level, but also at the equipment and system specification, validation and qualification stages. It proposes recommendations applicable to the whole industry.

A follow-up study has been awarded to the same Consortium in 1998 which aims at experimenting and validating the COCISPER guide on real applications, but also at updating it to take into account the Programmable Logic Devices (PLD) ant recent techniques such as the use of Virtual Components.

In addition, an evolution of the guide facilitating the access to information has been asked. A HMTL version is now developed and available.

INTRODUCTION

Progress in microelectronic technology has allowed the use of increasingly high-performance Application Specific Integrated Circuits (ASIC) for the benefit of systems. However, their use involves problems associated with the particularities of those integrated circuits and also from the characteristics of military and aerospace equipment and systems: Complexity, performance, reliability, cost, harsh environments, limited production lead times and long term availability for the durability of systems.

COCISPER, which stands for "Conception Circuits Intégrés Spécifiques et Pérennité», is firstly the name of a project seeking to draw up a methodological guide to ASIC and PLD designs with a view to ensuring system durability and control of the long term availability attributes surrounding development process. These are the fundamental objectives of the guide.

COCISPER is thus also the name of the industrial Consortium which is entrusted in the realisation of that project, with the support of French DGA. The Consortium comprises representatives of seven defence and aerospace sector companies, leaded by Matra BAe Dynamics, and the partnership of Aérospatiale Matra Missiles, Astrium, Sagem.SA, Thomson-CSF Detexis, Thomson-CSF Sextant, Thomson-CSF TTM.

Project objective is to pool experience and methods over a sufficiently broad industrial base to produce the operational recommendations, outline procedures and generic procedures forming the guide. They are based on the best methodological practice (state-of-the-art) to emerge from the sharing of experience and joint formulation of the new recommendations.

The guide is drawn up by industry, for industry. It is an operational guide: It is neither an imposed framework nor an additional constraint. On the contrary, it should enable everyone to develop their own procedures consistent with in-house development references. Depending on the nature of the requirements, the guide may concern system manufacturers, equipment manufacturers, in-house ASIC functions or design centres providing services, supply and production functions and contractors in development (CAD and software tool suppliers, founders).

COCISPER also wants to take advantage of the new quality assurance approaches developed in the electronics industry and thereby to promote, through the methodological guide, changes in practice. For example:

- Specify requirements first, not solutions;
- Define and characterise processes;

Paper presented at the RTO SCI Symposium on "Strategies to Mitigate Obsolescence in Defense Systems Using Commercial Components", held in Budapest, Hungary, 23-25 October 2000, and published in RTO MP-072.

- Do not wait for the final result before measuring how appropriate they are;
- Validate and react: do not consider the prototype to be the end of the project's life cycle…

OBJECTIVES OF THE GUIDE

However, their use involves problems associated with the particularities of those integrated circuits: performance, cost, low production volume, lead times, etc. These constraints arise also from the characteristics of military and aerospace equipment and systems: complexity, performance, reliability, harsh environments, limited production and durability.

As previously said, durability is, at this time, one of the main issue for military and aerospace equipment and systems. Contemplating system durability at ASIC level will mean either ensuring durability of the integrated circuit or maintaining the ASIC function at card level throughout the life cycle of the system.

In this context, COCISPER's objective is to draw up a generic development plan applicable to digital ASIC. It takes account of durability requirements at system level, development quality, and control of economic conditions. The flexibility essential to industrial competitivity is taken into account in those objectives.

Given that such a guide must command broad acceptance and be validated in real situations, the approach to drafting the COCISPER recommendations is based on the following objectives:

- to create conditions for acceptance of the guide outside COCISPER by targeting all potential users of the methodology, including civil industry;
- to validate application of the recommendations in practical experiments with ASIC development;
- to involve microelectronics educational and training institutes in order to evaluate how COCISPER's work can be used to assist training in the methodology of ASIC design.

This determination to interact with the players in the ASIC community must make this guide a living tool, capable of adaptation to the markets targeted and to developments in technology or the state-of-the-art. The work remains compatible with existing standards (e.g. ISO 9000) and does not, in any way, represent an additional constraint.

SCOPE OF THE GUIDE

It is illustrated in figure 1. The COCISPER methodological guide sets out to answer a number of methodological questions facing the ASIC designer and user community both from the technical point of view and from the practical and economic points of view.

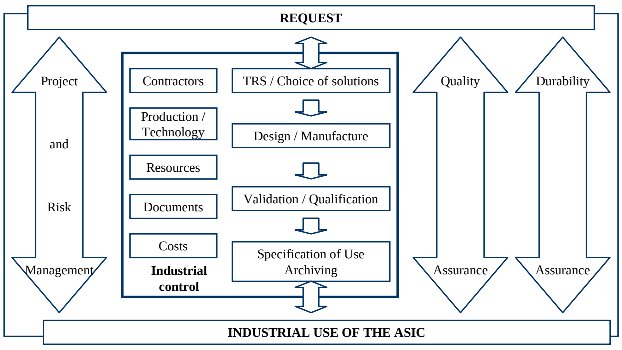

Figure 1 : Scope of the guide

From the technical standpoint, this methodological guide deals with all the points necessary to produce an ASIC, from the request made by the user to industrial use of the ASIC. It is constructed around the ASIC development cycle.

It takes account of all the problems associated with industrial control of that development cycle and the associated methodological support, laying particular emphasis on peculiarities specific to the ASIC. It identifies as clearly as possible the parameters that tend to degrade service and ultimate quality, giving recommendations regarding:

- the control of contractors,
- the process,
- the manufacturer,
- the tools,
- the documentation,
- and the costs.

In the context of the methodological support, it sets out all the aspects necessary to the smooth running of the whole project, such as quality assurance, durability assurance and of course project and risk management, for the ASIC is above all part of a project.

From the practical standpoint, this guide is directed at all those who come into close or remote contact with ASIC. To that end it offers a set of recommendations and information about its use, its specific vocabulary and mode of evolution.

THE GUIDE: CONTENT

The guide concerns a field, which may be summarised as follows:

- **Development flow**: Technical Requirement Specification (TRS), choice of solution, description of the functional design stages through to the physical design stages, specification of the interfaces with the founders and CAD tool suppliers, validation of prototypes, qualification of the ASIC for use, specification of use, and supply specification;
- **Support methods and activities**: ASIC activity management, ASIC project management, quality

management and quality assurance, durability management and assurance, quality control and industrial control, documentation management and industrial use of the ASIC.

Under those headings, the guide describes the flow of ASIC design - that is the operational view of development - and the methods used to manage and control that flow - they are the process support activities.

The Technical Requirement Specifications (TRS)

Two essential tasks must be performed before launching the design of an ASIC:

- drafting of the TRS
- a feasibility study and choice of solutions.

The TRS is a reference document in which the requester and the designer of an ASIC agree on the characteristics of the product. The TRS is consistent with the functional specification. It differs from the latter in that the functional specification expresses the requester's desires without ensuring that they are realisable under the prevailing technical and economic conditions. In the case of the TRS, the requester makes a commitment regarding his requirements and the associated constraints, and the designer a commitment regarding his ability to undertake development of the circuit with a guarantee of success. To this end, the TRS must state:

- the functional requirements and the environment conditions;
- the dependability requirements;
- the interface requirements;
- the design and production requirements;
- the product qualification and acceptance requirements;
- the conditions regarding verification of compliance with the requirements.

The TRS is a contract binding the customer and the supplier.

The feasibility phase (analysis of the requirement, exploration of concepts, etc) and definition phase (choice of concept and specification of requirements) must culminate in a first reference version of the TRS usable by the designer. Nevertheless, it would be a mistake to think that those involved in these (necessarily short but not too short) preliminary phases can grasp all the implications associated with implementation of a function in a circuit. It is therefore highly probable that this TRS will evolve during the design work. The whole problem is therefore to put in place solutions, which can control the changes as well as possible in order to maintain consistency with the initial definition on which the design centre embarked.

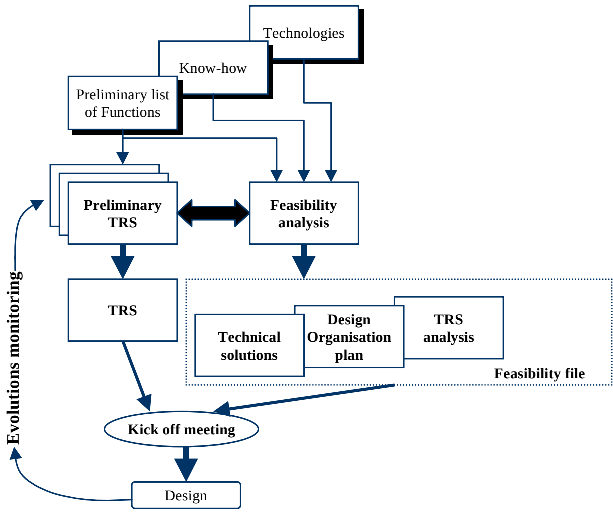

Figure 2: TRS and feasibility analysis

The Design and Prototype manufacture

The standard flow suggested in the figure 3 includes two successive phases entitled design and manufacture respectively. It is applicable in broad outline to all types of ASIC, including programmable ones, subject to a few adaptations such as, for instance, the elimination of certain tasks, or their replacement by other dedicated to PLD.

The design phase divides into three stages, namely, in chronological order of execution:

- preliminary design,
- structural design,
- physical design.

Owing to the strong interactions between preliminary design and structural design, these first two design stages are not always treated separately in practice. As a result, no precise formalism at their common interface is defined.

The manufacture phase described relates solely to mask-defined ASIC. In the case of PLD, this phase is either deleted (this is the case with circuits programmed in the application) or replaced by programming by means of a dedicated device.

Every phase yields elements in conformity with the input documents, which have, themselves, been validated. The information in the TRS is assumed to have been validated vis-à-vis the system. Consequently, the validation operations performed during design are intended solely to ensure that the various descriptions of the ASIC conform to the requirement stated in the TRS. Similarly, the various tests performed on the component during the manufacturing process serve only to ensure conformity with the software model resulting from the design process.

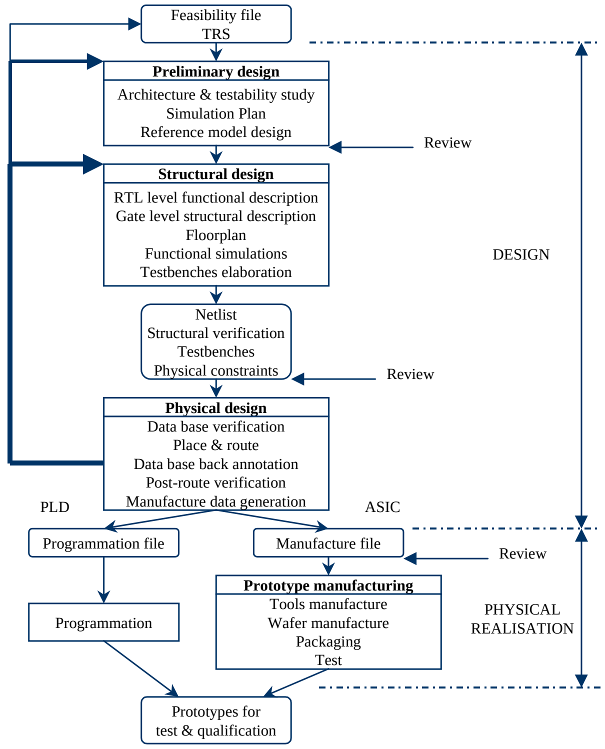

Figure 3: Design and prototype block diagram

The Validation

The Validation phase is part of the general ASIC design flow. The status of "validated ASIC" is acquired when all the requirements listed in the TRS are fully satisfied:

- relatively to the virtual product, by using simulation techniques,
- relatively to the real product, through an overall validation process.

It allows checking the complete match between both virtual and real products. However, the founder must qualify the technology, the manufacture process and the libraries.

The virtual product is the result of the structural design phase. It includes a structural netlist *but also* the associated test vectors.

The real product is the result of the manufacture phase. In the guide, this chapter only covers its validation. The verification of the virtual product is fully described in the chapter of the design phase as it is usually performed by designers or by a specialised team closed to the designers one.

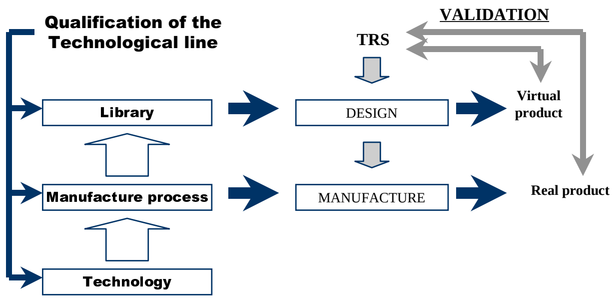

Figure 4: Localisation of the Validation

Industrial control issues

The development process consists of a number of stages leading to the supply of ASIC that meet the requester's requirements. If the development's industrial environment is well controlled, development may be linear and culminate in the expected result. Experience shows that the process is disrupted by external factors inherent in the industrial development environment. The "Development process control" sets out ways of controlling that process.

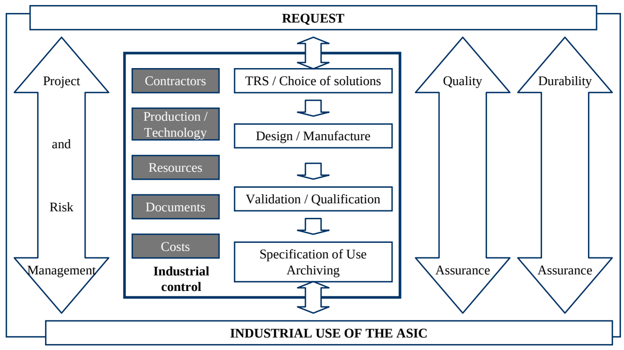

Figure 5: Scope of the Industrial Control

The shaded boxes in the figure 5 indicate the scope of industrial control in relation to the scope of the guide as a whole.

Control of contractors is based on the principle that the development of ASIC involves a succession of complementary specialities. Those may be found within the industrial firm developing the ASIC or among its contractors. To ensure proper control of them, a dynamic mode of interfacing must be established between the industrial firm and its contractors, based firstly on principles common to all the specialities and secondly on particularities of certain specific fields of activity. The specialities are grouped around four main areas of activity:

- design,
- analysis / characterisation,
- manufacture,
- and tools / libraries.

Control of the production technology and the founder represents an unavoidable special case in the development of ASIC. The methodology is based on general control of manufacturers, which relies on consolidation of the aspects of quality assurance applied by the manufacturer:

- generic qualification of combinations of manufacturer and production technologies,
- the establishment of quality contracts between the manufacturer and the industrial firm which is developing the ASIC.

This is to take place in a context separated from the projects, but obviously before they need any support from the founders. At this point, it should be emphasised that the ASIC designers have to get into contact with them as soon as possible, that is at the beginning of the design phase in order to make sure the design will be fully compliant with any founders' rules. It also means that any internal procedure must be soft enough to allow this adaptation, and some design rules must be set up to assure portability from one technology to another one.

Control of resources centres on two main categories used during development of ASIC: CAD tools, and test resources specific to ASIC. In the case of the CAD tools, the specific aspects of those that are technology-independent and those that are dependent on a particular technology are identified. As control of these tools is particularly critical to ASIC development, a number of provisions designed to limit the risks they generate are presented in the guide.

Project management

The lifetime of a system is the period covering the system's development, refinement, production engineering, production, delivery and maintenance.

During the system's life cycle, ASIC project management traditionally covers development of the ASIC, from specification of the circuit (on the basis of the system specification) to delivery, validation and qualification of the prototypes.

To a lesser extent it also covers the system-refinement and production-engineering phases (through the production engineering of the system's components).

The need to take account of long-term durability problems, as well as developments in technology and design techniques naturally means that ASIC project management has implications for and is affected by the equipment production and maintenance phases.

That is why the Consortium has chosen to put into perspective the areas of concern of ASIC design team leaders wishing to develop their activities towards improving the service provided for the users.

First of all, in the light of the "system" or "programme" view of project management, we shall define more clearly the relationship between ASIC development and the requesters' needs in terms of visibility and assurance of the smooth running of the project. This will lead us to define the modes of interfacing between a project team and an in-house or external ASIC design centre.

Therefore, a precise distinction is to be made between the terms:

- "ASIC project management", which designates the management of a team designing application-specific integrated circuits,
- "project management", which designates management of the user or requester projects. The term "requester project" should be understood here to mean the project in the context of which one or more ASIC are being developed.

In addition, the Project Manager will also have to assure:

- the relation with Purchase managers and suppliers, in particular the founder and tools providers to get the necessary information on they strategy
- the relation with the human resources. This point is one of the most important as the consequences of any decision have short but also long term impacts
- the promotion of the technology.

Also, the Project Management is involved during the BID proposals.

According to the organisation of the company, one or several people can handle all these aspects.

Accommodation of Risks

ASIC technology is often associated with a high notion of risk… This issue, however, can be addressed at the design level, but also by applying a rigorous project management.

ASIC development plan: Management - ie. Minimisation - of the risk associated with design necessitates, ideally, keeping development within the strict framework of the team's area of know-how. However, this principle frequently conflicts with the need to adapt that area to respond to new requirements or to apply new techniques if these alone will allow the planned circuit to be constructed. At all events, the risks associated with the particular situation of the ASIC contemplated must be identified, so that the specific actions to minimise those involved in development of the ASIC can be defined. Such analysis is necessary to lay down and refine the development plan.

Impact on cost: The general principle of risk management in an industrial context is to compare the potential cost of the setbacks that may be suffered as a result of the identified risks with the cost of specific actions to cover them. One also has to estimate the probability of the event feared occurring and the presumed effectiveness of the specific action envisaged to avoid the setbacks. These estimates are generally not strictly quantifiable and must be based on past experience.

To illustrate this principle, the quantity of work involved in validating the design before it is sent to the founder must be measured against the cost and impact on lead times of re-manufacture, which would be necessary in the event of an error. In the case of PLD, the absence of specific manufacturing limits this risk.

Impact on schedule: Besides the frequently direct and considerable impact of not keeping to the design schedule on the development cost of the product using the ASIC, other indirect and equally substantial impacts may be attributed to poorly controlled design time:

- reduced profitability of the project through late introduction of the product and delayed return on investment;
- in a competitive situation, loss of market share, or more directly the penalties incurred in the case of a pre-existing order;
- loss of credibility…

Ensuring the deadline is met is thus a specific action, and the scale of the effort devoted to it should be proportionate to the risk. The risk is all the greater, as the ASIC is frequently, by its very nature, in the critical path of the project that commissions it.

The difficulty of this task arises from the enforceability of all the hazards that may upset the smooth progress of design, particularly in a rapidly changing technical field. In addition, there is extensive dependency on third parties (founders, CAD tool suppliers, etc), that limits the total control of timing.

Impact on feasibility: The risk of discovering belatedly a problem that calls into question the very feasibility of the intended function must not be underestimated. Its impact on cost and timing is direct and serious. That is why the feasibility study must be conducted carefully and must culminate in both a TRS and a technical solution including a development plan, which must be fully consistent with one another. Experience is therefore crucial during feasibility analysis.

Quality and Durability assurance

Quality assurance: The description of the process of developing an ASIC incorporates activities contributing to ASIC quality assurance, i.e. primarily helping to confer appropriate confidence that the ASIC will meet the requester's requirements. These activities are those which are fully integrated with current development practices and which it would have been artificial to separate from the other stages of development. Examples include simulation activities, design rules verification, etc. The process itself as defined in the guide thus already has a quality assurance dimension.

Other major topics are also important in the context of ASIC, such as industrial control.

Durability assurance: Obsolescence in ASIC is a constant concern for industrial firms, as technologies come to the end of their lives and others no longer meet the economic criteria of the market. Manufacturers are obliged to rationalise their means of production to increase their profitability. The longer the period over which the equipment concerned is produced and maintained, the more critical this context becomes. In particular, the slightest change in the ASIC or the definition of the item of equipment necessitates a qualification process, which is often long and costly.

A set of coherent recommendations constituting a method of ensuring the durability of an ASIC function can be proposed. By "function", we mean a combination of functional behaviour and performance. The method relies on two essential levers controlled by the industrial firm: the choice of solutions and the design. The object is to ensure that the customer continues to have available a system meeting a requirement, rather than a system complying with a definition.

This concept of durability of function is essential to the control of ASIC durability. It forms part of a customer / supplier relationship based on a commitment as to results and on definition of requirements arising from needs at each level of complexity of the system, down to component level. In particular, a durability strategy cannot be conceived independently of the rest of the system. It must be the product of a system durability strategy deployed at component level.

Durability assurance has two aspects:

- Preventive action to ensure durability of function: This forms part of the initial development of the ASIC and can be described as a set of applicable recommendations to facilitate re-design of the ASIC and maintenance of its qualification.
- Action to deal with component obsolescence to make sure that a solution is available to ensure system durability.

It may be noted that the durability of an ASIC is highly dependent on the manufacturer's ability to ensure durability of the production technology, i.e. that of the component and the function. The same is true of the choice of solutions presented above as one of the levers essential to achievement of durability.

Relationship between Quality and Durability assurance: Quality assurance may be considered to encompass all the steps taken to ensure control of the development process and the achievement of a solution satisfying the customer's requirement. One could define its ultimate objective as fitness of the solution for the purpose. As a complement to that, durability assurance may be defined as all the steps taken to ensure the availability of solutions, at a controlled cost and within a controlled time, that satisfy the customer's technical requirement throughout the life cycle of the function. The ultimate objective in this case is the availability of suitable solutions.

The figure 6 illustrates this principle. For a given ASIC, the shaded area represents the provisions to be put into

effect, with no regard for durability requirements. The upper curve indicates the provisions to be put into effect to cover all the requirements, including durability.

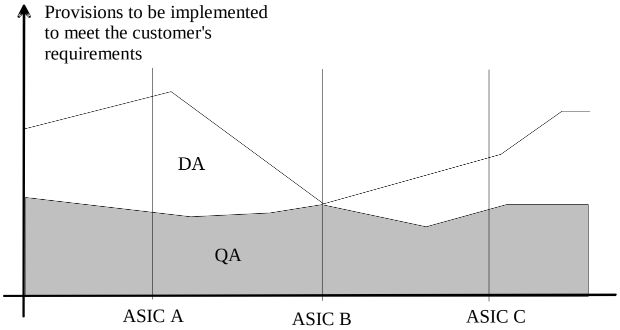

Figure 6: Quality assurance vs. durability assurance

The scope of the provisions depends to a large degree on the requirements relating to the life cycle of the ASIC in question. In the figure 6, ASIC A corresponds typically to a long life cycle (an armament programme, for example), ASIC B to a short life cycle (with no durability constraints), and ASIC C to an intermediate life cycle.

Insofar as availability of solutions that meet the technical requirement is itself one of the customer's requirements, durability assurance could be considered as a facet of quality assurance. However, as durability assurance is a relatively new concept and constitutes one of the guide's major concerns, it has been identified and dealt with separately.

THE HTML VERSION

The HTML release has been organised in such a way that the main topics are directly accessible from the Welcome page, as shown on figure 7.

Guidelines related to quality assurance and durability assurance are integrated and available directly inside the ASIC design process flow with the help of following icons AQ et AP. Recommendations dedicated to programmable logic devices are accessible with PLD.

Therefore, it allows anyone to address directly one (or several) question(s) without the needs of searching through a complex process. However, it remains possible to exploit the guide in a very linear classical way, using the guide table of content.

CONCLUSION - DEPLOYEMENT

Given that such a guide must command broad acceptance and be validated in real situations, the approach to drafting the COCISPER recommendations is based on adhesion through utilisation.

The determination to interact with the players in the ASIC community must make this guide a living tool, capable of adaptation to the markets targeted and to developments in technology or the state-of-the-art. The work remains compatible with existing standards (e.g. ISO 9000 / AQAP100) and does not in any way represent an additional constraint.

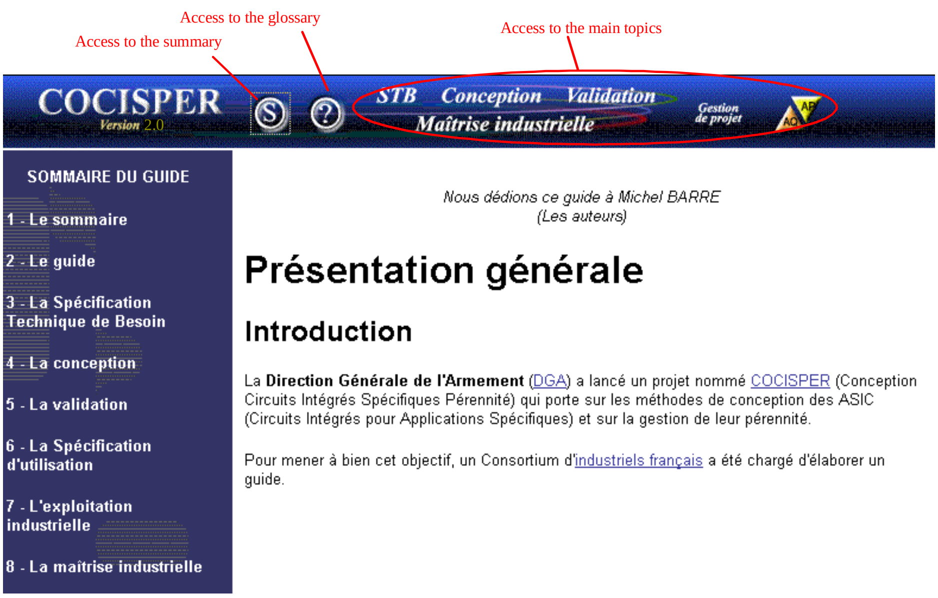

Figure 7: COCIPSER: The Guide – Welcome page

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Minimizing the Software Re-design in Obsolescent Radar Processors with Functional Radar Simulation and Software Workshop

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Abstract

Signal and Data Processors are the sub-assemblies which are the most likely obsolescent parts in modern airborne Radars. As their architecture is based on multiple parallel COTS processors, the implementation of the algorithms in these processors is a costly and time consuming task which represents the most significant part of the cost when the sub-assembly has to be replaced due to component obsolescence.
The use of a powerful software workshop is the way to dramatically cut the cost of the software redesign by an extended re-use policy.

A significant improvement in the radar development cycle can be achieved through simulation techniques. These new tools and methodology enables to reduce costs and to shorten the radar modes development cycle.
During the phase of specification, a functional radar prototype is developed, requirements are defined, and testing procedures are developed. This functional radar prototype is completely independent of the processor hardware and survives to COTS obsolescence.
During the phase of on-board functional software development, the functional prototype is re-used to simulate the machine architecture (processors in parallel, communications, …) and the algorithms are optimized for the target processor hardware.
During the testing phase, a cross test between the functional prototype and the on-board functional software can be performed by the re-use of the testing procedures. Also, the flight tests can be prepared by the simulation of the scenario to be played.
The designer can be assisted by a tools for all this developments.

1. Introduction

New radars or new radar modes become more and more complex. The sophisticated signal processing algorithms and the real time requirements need multiple processors machines. To reduce the cost of radar development, to shorten development cycles, and to cope with obsolescence problems of the processor hardware, a new methodology based on simulation and re-use of simulation software is applied in THOMSON-CSF DETEXIS for some years.

The main means of this new methodology are:

- further use of simulation techniques in the phases of system specification and design,
- re-use of simulation software modules in embedded software,
- set up of two workshops (simulation and processing machines).

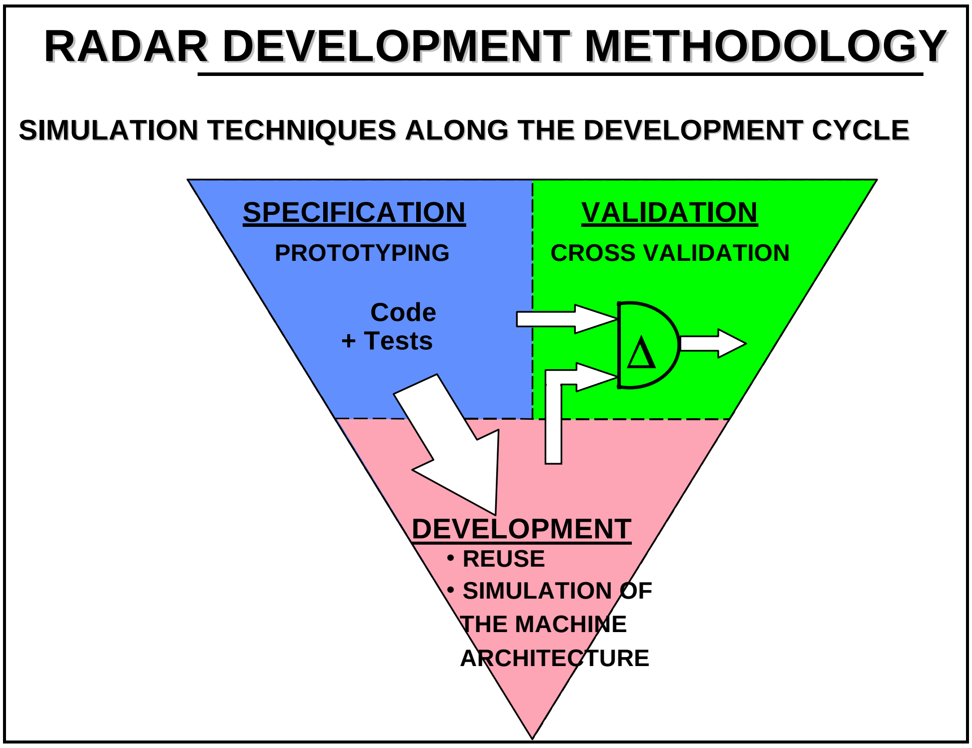
In a classical approach, 4 distinct software were developed:

- advanced studies software to design algorithms,
- function modelling software for radar design,
- applicative software,
- data analysis software to process in-flight recorded data.

Paper presented at the RTO SCI Symposium on "Strategies to Mitigate Obsolescence in Defense Systems Using Commercial Components", held in Budapest, Hungary, 23-25 October 2000, and published in RTO MP-072.

The new approach consists in re-using a same software for different tasks. In fact, 3 out of these 4 software run on a host machine (work station); the software used for prototyping the radar can be exactly the same as the software for analyzing the in-flight recorded data. The software for advanced studies can be re-used for the radar design. So, on the host machine (workstation), we can have a single software (or a re-use of code). This software being completely independent of the hardware, it is not affected by obsolescence. For on-board software, the problem is quite different : this software runs on a target processor which implies a lot of constraints. The solution is to re-use the software running on the workstation for assisting the designer to develop the on-board software : source code can be re-used.

To illustrate the simulation, we can consider a 3 phases development cycle: specification, on-board software development, and validation.



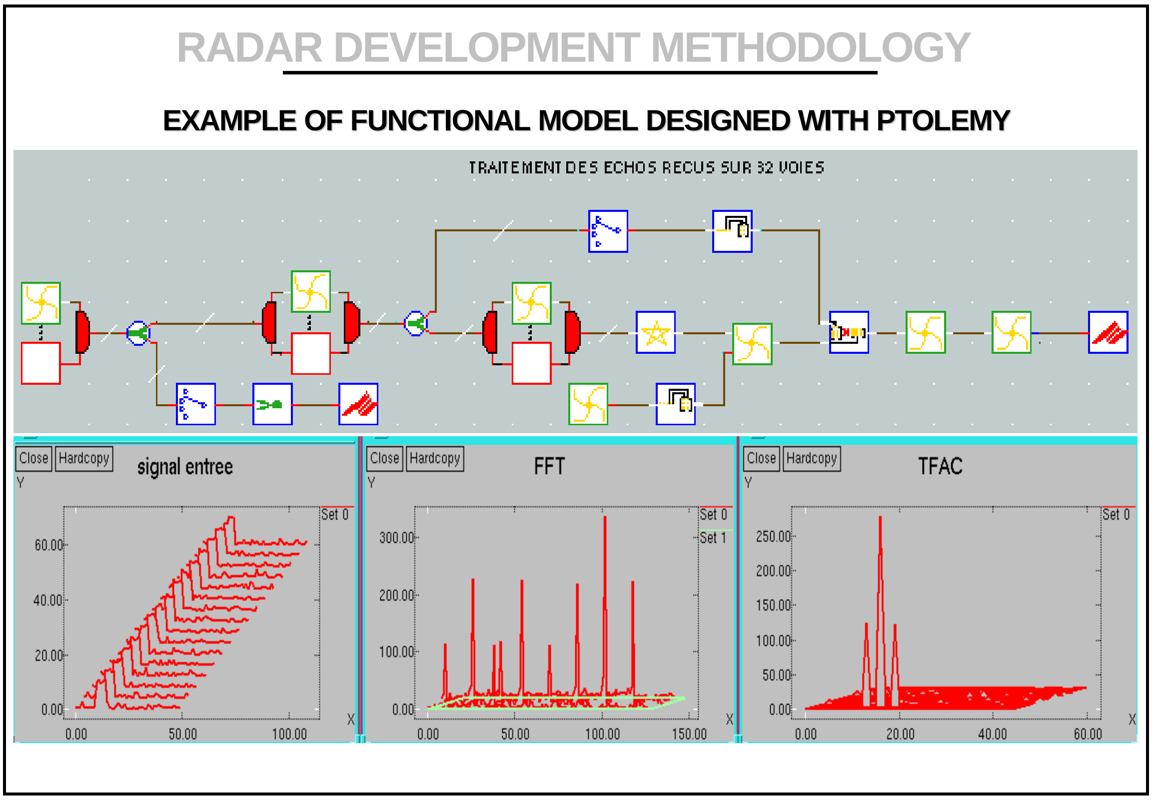
Simulation techniques used during the main phases of a development cycle.

2. Virtual prototyping

During the specification phase, simulation can be used for prototyping the virtual radar on an host machine (workstation). This radar prototype allows to:

- design the functionality of the radar mode and to define the interfaces between the different modules of the radar,
- specify the exact algorithm which is needed (to avoid overspecification),
- evaluate the radar performance, such as resolution for an air to ground mode or detection range for an air to air mode,
- and finally define the validation procedures. The prototype software is verified with these testing procedures, which are the functional reference for the radar mode. These procedures will be re-used at the validation phase.

This virtual prototype is independent of the hardware technology and is represents the “reference” of the radar.
Then the designer can be assisted by a tool for the development of the radar prototype software: a tool (such as Ptolemy) can facilitate the designer’s work. A toolbox is created with a library containing signal and data processing algorithms. The designer can build the prototype and takes each algorithm he needs from the toolbox and then links together the algorithms with a specific tool. Then on workstation, final output or intermediate output can be verified.



Example of functional model with the tool Ptolemy

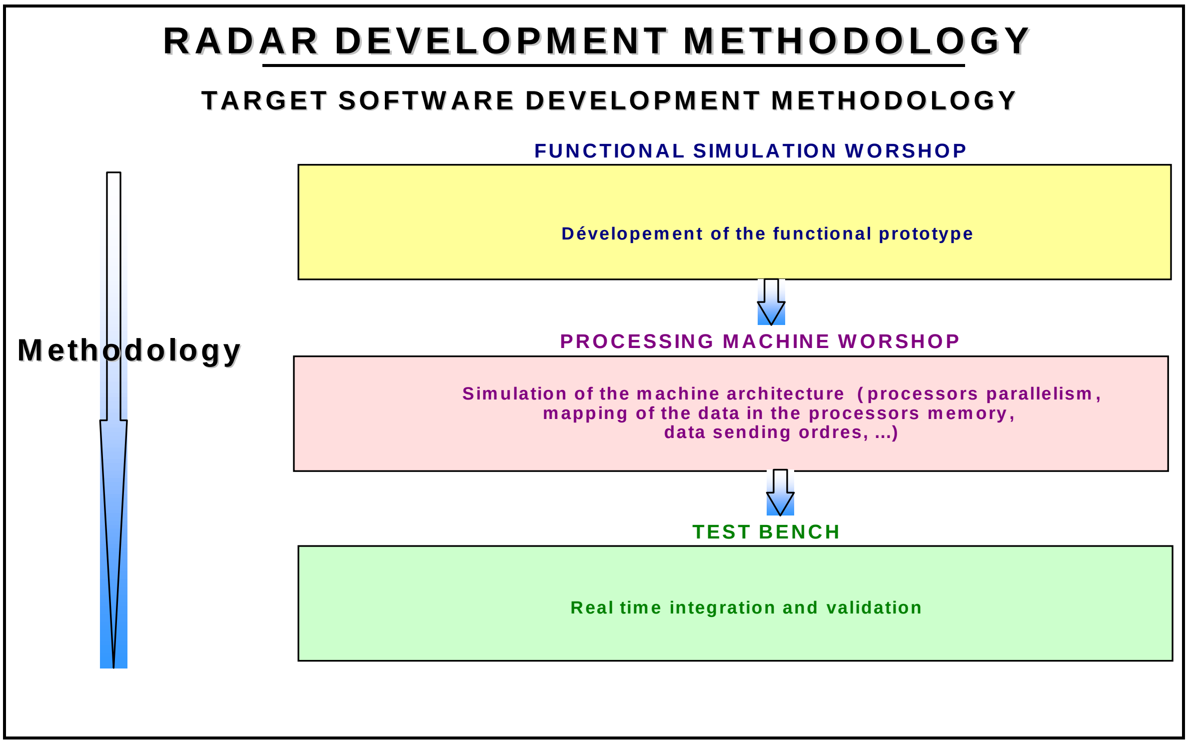
3. On-board software development (new hardware design)

The second main phase of a radar mode development is the on-board software development. With the virtual prototype, a signal and data processing software is available; this software runs on workstation (single processor environment). At the end of this phase, the on-board software must run on a multi-processors machine. To re-use the virtual prototype software, the methodology is as followed:

- in a first phase, a model, matched to the processor architecture, is developed on the basis of the functional model, taking into account the architecture and the characteristics of the machine.
- in a second phase, each algorithm is compiled and optimized for the target processor. For each algorithm, the number of cycles and the memory size must be known. This is possible if the processor accepts algorithm in a language such as C or C++, …which is the case of new COTS DSP or processor.
- In a third phase, the software is linked and loaded in the target machine and can be verified on the test bench.

This methodology is of interest also because it enables the designer to disconnect the problems : the algorithm problems are seen during the functional model development; the parallelism, memory mapping or communication problems are seen during the development phase of the model matched to the target architecture. When working on the hardware test bench, all these problems are solved and the designer can concentrate on real-time problems.

The designer can be assisted by tools to optimize the algorithms implementation on processors. For example, a tool can measure the workload ratio for each processor or evaluate time for data processing . Some tools also generate the source code for each processor and software for communication between processors or between the different memories of a processor.



The different phases of the on-board software development

4. Validation

The third main phase of a development cycle is the validation. During this phase the testing procedures, defined at the specification phase (and run on the functional prototype on workstation), are played on the radar on the test bench, and the both results can be compared. By that way, the functional requirements can be verified.

Always in the phase of validation, simulation techniques can be used for assisting flight tests.

- The scenario that will be played in flight can be played first on the virtual prototype on the host machine. So, flight tests can be prepared, and results can be analysed.
- Simulation techniques allow evaluation and validation in a complex environment. For example it is possible to add on recorded data, some synthetic data: targets, jammers…

5. Conclusion

In conclusion, using simulation techniques all along the development cycle enables to design the functional prototype of the radar which is the reference of the radar architecture, modes and algorithms. As this reference is not technology dependant, it can be re-used when the hardware has to be upgraded minimising the redesign and validation cost. On the other hand, libraries of algorithms, subassembly models and workshops can be re-used for new radar product developments to design the new functional prototype. It also helps the designer to develop the on-board software, to do cross-testing between the functional prototype and the on-board software, and finally to prepare the flight trials.
A cost saving (and time saving) by a factor 2 to 3 has already be demonstrated either for new developments or for processor upgrades.

Commercial Off-the-Shelf Software and Simulation Tools

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Summary:

In this paper the author will present the arguments supporting the case for using Commercial Off-the-Shelf Software and Simulation Tools (COSST) in major defense systems, whether for actual combat, or for embedded training purposes. Whether the objective is a service life extension, new development, or an upgrade to certain system level functions and operations, COSST have come to represent the solution when budgets and time scales are tight and engineering staff are becoming harder to come by. The author will describe how his company's tools have been layered over the engineering, simulation, test and analysis processes at major defense firms to improve reuse, assist in knowledge capture, and to produce results in major weapons systems programs.

Introduction:

Virtual Prototypes, Inc (VPI) has over 15 years experience as the market leader, working with 350 corporations, focused on the successful deployment of Commercial Off-the-Shelf Software and Simulation Tools (COSST) in the Aerospace and Defense and Automotive industries. Whether the objective is Simulation Based Acquisition, Lean Manufacturing, Collaborative Engineering, Virtual Product Development, or Synthetic Environment Based Acquisition, COSST have come to represent the solution when budgets and time scales are tight and engineering staff are becoming harder to come by. I will present today some of the economic arguments behind the move to COSST by major Aerospace and Defense companies, and how the VPI Enterprise Software Framework (ESF) can be applied to the engineering process.

In the past, VPI customers successfully used one or more of our tools on numerous programs. Until recently, this has been the norm. With human-machine interfaces (avionics and vectronics in Aerospace & Defense (A&D), vectronics alone in Automotive) becoming an increasingly virtual product; i.e., software with performance limited only by the computer hardware environment, it is becoming important to capture the knowledge of the engineering staff involved in its creation. Establishing an integrated, common set of design and test tools with VAPS, FLSIM, STAGE, SEQUOIA and third party products from companies such as Motorola and GreyStone Digital Technologies, starts the critical process of knowledge capture and conservation. This process is contained within the system development, integration and test, flight test (A&D), and training system development (A&D) functions.

It has become increasingly clear throughout the last decade that the visualization and simulation technologies embedded into the VPI virtual prototyping platforms are in direct alignment with the desired goals expressed within strategic business initiatives of Aerospace and Defense and Automotive customers:

- Cost reduction
- Schedule compression (Time to Market)
- Risk mitigation (Focus on Target Market Needs)
- Knowledge capture and information re-use

Economic Reality:

One may ask why the VPI ESF is being implemented in these companies? From the VPI perspective and its experience-base, the VPI ESF has been successful because it meets the strategic business initiatives outlined above. The concept has been proven out over time. The risk of implementation has been significantly reduced/eliminated as a result of VPI successes at many customer sites. This has been accomplished in many complex VPI customer environments such as:

- Lockheed (F-22, C-130, MH-60, F-16)
- Elbit, Litton (SH2G)
- BAE/DASA/Alenia (EFA)
- BAE/Boeing (Wedge Tail)
- Boeing Bold Stroke (Avionics Upgrade Programs)

Interestingly, the motivations to implement the more streamlined and modern VPI ESF process were typically driven by unrealistic, if not suicidal, timeframes due to the inability to hire personnel coupled with the untimely loss of key subject matter experts. We have repeatedly seen highly specialized avionics engineers (e.g. a 17-year veteran) decide to start a new career at a ‘dot.com’ company and the “avionics expertise” walked right out the door.

Paper presented at the RTO SCI Symposium on “Strategies to Mitigate Obsolescence in Defense Systems Using Commercial Components”, held in Budapest, Hungary, 23-25 October 2000, and published in RTO MP-072.

We know these vicious stories because this is a recurring theme in the entire defense related industry, and it is beginning to spill over into other sectors such as Automotive. We have witnessed them at Raytheon, BAE, Matra/BAE missiles, Alenia and, as of lately, in MATRA/DaimlerChrysler Aerospace (EADS). We have personally watched this breath-taking exodus injure the quality, and knowledge base of the work force. Expertise continues to “walk right out the door”.

VPI has built its business model precisely around this market condition:

We want to help customers retain expertise through the employment of the VPI ESF and achieve their demanding schedules. We deliver a solution that allows customers to maintain a reduced staff and an appropriate level of accumulated expertise, in spite of the exodus. We are interested in helping our customers get 40%, 50%, 60% better (e.g.16 months reduced to 9 months, doing the work with 300 engineers instead of 500, eliminate re-work in software code development, etc., etc.). We are interested in shocking the system to a new level of productivity and information re-use.

Getting the best of both the worlds:

It is fully recognized that that our customers have developed much quality custom software internally. This includes efforts from many years resulting in an array of models for flight simulation, radar, navigation, etc.

As we have seen however, the increasing burden of maintaining both the topic-specific software and the framework that houses the basic components has become uncomfortably expensive. Most of the framework for legacy software has not been migrated to modern programming languages or new computational platforms. As key staff member attrition takes hold, the flexibility of using this legacy infrastructure becomes more difficult daily. The situation is complicated by the use of government created software tools, which may also be out-of-date or generally are awkward to manage/modify. These conditions have driven an unstoppable movement to COSST-based tools.

Specifically, how does a customer reap the benefits of their current proprietary efforts and the benefits of COSST?

Rather than continuing the current engineering practice of having many integrators involved in various parts of the system development process, as shown in Figure1, Virtual Prototypes, Inc. assists customers in the creation of an Integrated Desktop Prototyping, Design, Simulation and Testing Environment (IDPDSTE) as shown in Figure 2. Now, several large customers are moving in the direction of using the entire set of VPI tools, in a flexible framework, to respond to enterprise goals such as LEAN Engineering and Optimizing the Value Stream. By supporting this move, VPI is presenting a solution that benefits many programs throughout the life cycle of each program and its derivatives. COSST are moving out of the realm of "valuable point-solutions” to “strategic enterprise-solutions" within the business process.

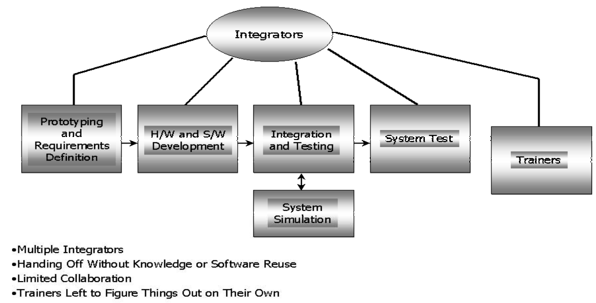

Figure 1 - Existing System Development Process

The proposed solution offered by VPI allows Customers to get the best of both worlds. First, we build a framework that integrates the existing subject matter specific software into a common and modern architecture. This architecture is the VPI ESF. It is COSST-based and is flexible to allow for changes through time. It is fresh and modern, and allows for years of typical framework creation to be accomplished in a few months. The outcome retains the valuable customer legacy development efforts, yet inserts these pieces into a modern and contemporary low-maintenance framework.

The result is that customers will be able to re-direct their efforts to subject specific content and diminish involvement in software maintenance and enhancement. The engineers will do the engineering and VPI software will maintain the framework.

It is interesting to note that almost all VPI customers have significant investments in legacy tools. It has been shown that, in spite of the investment in that area, there are significant gains that can be incrementally obtained by further automating the engineering process. This is accomplished by implementing the VPI COSST Framework and leveraging existing legacy models (e.g. flight simulation, radar, etc.).

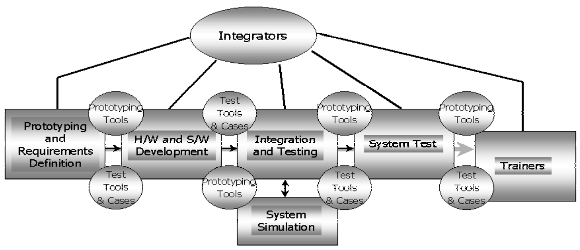

Figure 2 - Integration of Common Tools across the Engineering Process

Re-using Knowledge and Information:

Reuse of Knowledge and Information is the key to success. As a result of implementing a framework that allows for information re-use, many redundant efforts are eliminated and a task is done once and is then available for access in future months and years by other groups. It should be noted that this continuity and information re-use is possible even though there may be significant turbulence in staffing.

Additionally, the VPI Framework allows for all the knowledge and information to be passed along the Value Stream in a contiguous and re-useable manner.

The thought of a new framework technology that allows for dramatic gains in the triangular management of time, cost and risk will not be received well by all. People at many levels will be "protecting their local empire" and may resist this proposal. This is not a shock to us; we see it daily.

Other groups of leaders and "change agents", who are interested in achieving 20-60% improvements and "shocking" the system will endorse it. We have done this elsewhere in equivalently complex environments. As much as those who are protecting their empires will argue this point, it is fact, and is not a debatable topic. However, during these transitional times when empires are being protected, the need for high-level management support is crucial.

Process:

Virtual Prototypes will integrate FLSIM, STAGE, VAPS and our other software products into an enterprise framework. The purpose of the integration will be to create a seamless integration of tools permitting the early identification of design problems, reallocation of requirements, and sharing of information across specific knowledge domains during avionics development. This integration will focus on creation of a desktop environment focusing on integration of these design and test tools, with existing customer proprietary tools where necessary, across the existing avionics life cycle (software development, testing, training) engineering process. The aim is to initially shadow the existing customer processes and overlay the tools onto the process to aid in the knowledge capture process as shown in Figure 2. Part of the emphasis, as shown in Figure 2, is to more closely integrate the Training segment with the rest of the processes, shown by gray arrow across all five major sub-integrator blocks.

Code Generation Automation and Common Test Environment:

The advantages of undertaking this effort are Code Generation Automation (CGA) and a Common Test Environment (CTE) from Desktop to Simulator to Aircraft. The advantages of code generation automation are shown in Figure 3 and include:

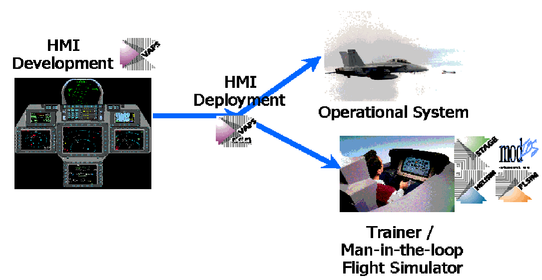

Figure 3 - Code Generation Automation Advantages

- Retention of the programming knowledge of the program as mentioned above
- The ability to have the staff focus on optimization of the value added tasks such as mission critical skills.

Code Generation Automation:

Generation of code from the tools during the prototyping stage of development provides the means for elimination of rewrite over the engineering process by the furtherance of reuse. Reuse of generated code ensures the viability of code before integration and testing and provides a means of up-front validation. The visual nature of prototyping with tools supports the "Art to Part" process within the Virtual Manufacturing paradigm. The tools also eliminate the present engineering practices of reconstructing the code at each intermediate process of the project life cycle. The inclusion of the Design Documentation tool with VAPS increases performance by permitting the automated generation of design documents for use throughout the project life cycle by an integrated product team. The prototyping tools also support the embedding of safety of flight critical rules prior to the code being generated.

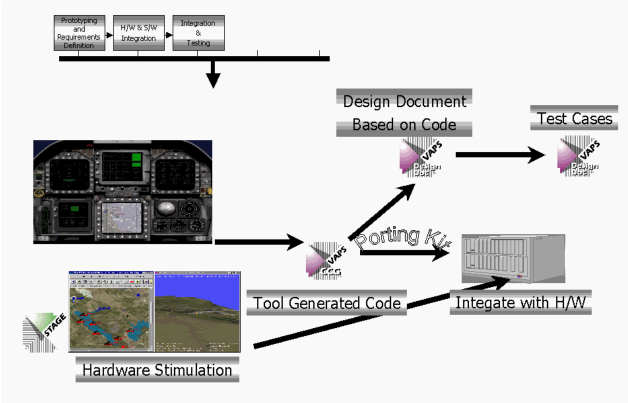

Figure 4 - Code Reuse

Common Testing Environment:

Additionally, this Common Testing Environment brings a level of consistency that has been missing in avionics development in the past. The CTE will provide for reuse of test cases, a sort of data fusion, as well as permit the optimization of resource utilization during testing by reducing or eliminating bottlenecks in scheduling test resources. The CTE supports the performance of full functional testing within a synthetic environment. The CTE envisioned by the integration of VAPS/FLSIM/STAGE creates a shared test environment that can be reconfigured for each process (Figure 5). The CTE creates a repository for a common database of test cases, thus increasing consistency of results across the process. Fully, a 20% to 30% reduction in support personnel is possible.

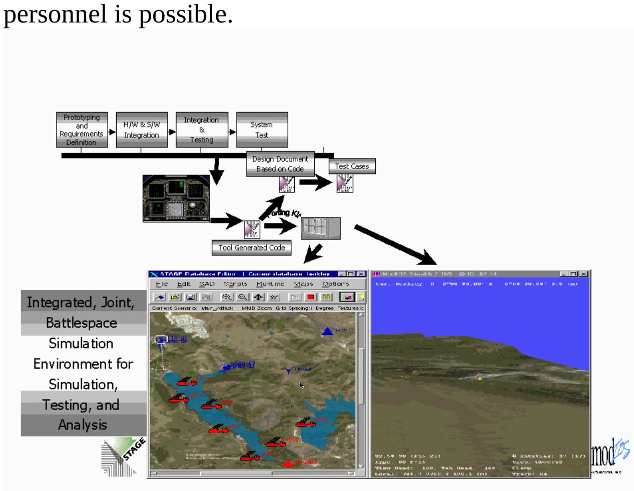

Figure 5 - Fully Integrated CTE with Synthetic Test Environment

Linkage to Support and Training Systems:

If one goes back to Figure 1, it is shown plainly that the Training/Support Systems portion of the overall Systems Development process has no clear linkage as one traverses prototyping and requirements definition, hardware and software integration, integration and testing (including flight test), and system testing. Training/Support Systems is "left to fend for itself" for design information, performance data, and code. Often, the training systems designers write their own code due to a lack of information flow and/or to maintain a delivery schedule consistent with weapon system delivery. With the type of ESF being shown, this will no longer be the case. The Training/Support Systems group can leverage directly from the knowledge capture taking place across the system development process through the use of the same common tool set. The avionics software will be identical to that produced during prototyping and requirements definition and then reused throughout the remainder of the system development process via automated code generation. By sharing like synthetic environments, Training/Support systems will be participating in the knowledge capture process and will reap the benefits of code and database reuse. This can provide the same 20% to 30% productivity increases as expected in the overall system development process. Figure 6 depicts the expected end-to-end results.

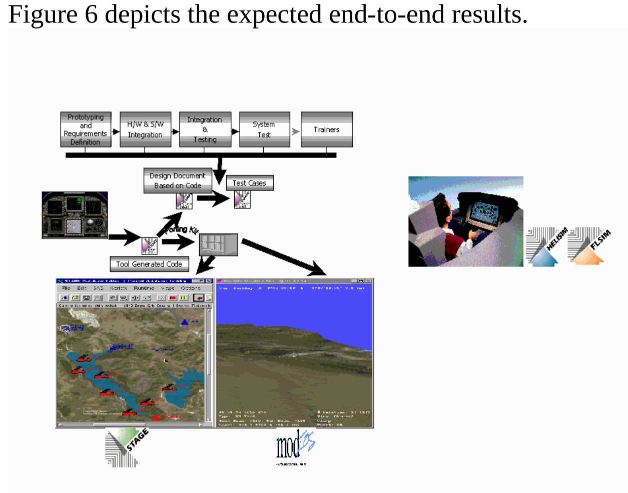

Figure 6 - End-to-End Results of Utilizing Code Generation Automation and a Common Testing Environment

How the VPI ESF Mitigates Obsolescence in Defence Systems:

First, the VPI ESF is composed entirely of Commercial Components, or what you would call Commercial Off-the-Shelf (COTS) software. Second, Human System Interfaces are one of the largest drivers in any weapons system or command and control system development. Third, these Human System Interfaces frequently undergo the largest number of modifications or upgrades in the life cycle of a system.

By using tools, which generate code in a manner that can be qualified for flight, industry and government will save between hundreds of thousands and millions of dollars upgrading avionics systems in the future. The reason is simply the fact that tools will eliminate many of the tedious hand coding steps currently performed by engineering staffs today. Other benefits of tool use are the ease of making changes and reducing risk. Technical risk is reduced through machine generation of the code

(machines do not get creative). Schedule risk is reduced by the fact that code generation is quicker and less expensive than hand coding, thus a shorter schedule can be supported.

On July 24th of this year, Frost & Sullivan (http://www.frost.com) published a report indicating significant upgrade programs in the military avionics markets in the United States and Europe would lead the industry through the next few years. Instead of procuring new equipment, air forces in these countries will maintain older fleets of aircraft while investing much of their budget on avionics and electronic warfare upgrades. Virtual Prototypes believes its tool based ESF solution can keep these upgrades from costing more than initial estimates. ESF can also reduce the probability of schedule delays and diminished functionality upon delivery.

Furthermore, the introduction of new fighter planes and the advent of Global Air Navigation System/Global Air Traffic Management will drive avionics upgrades in other parts of the world. The military air transport avionics market is also driven by the need to upgrade and develop better airlift capabilities around the globe. Recent conflicts have demonstrated the vital role of airlift in military operations. Europe and United States are at the forefront of development and upgrade programs for their fleets. Virtual Prototype's believes that without a robust solution to the brainpower drain, these countries will be hard pressed to complete these upgrades in a timely manner. Again, the ESF solution can help.

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The Obsolescence Management Based on a "Pro-Active" Approach in Conjunction with a "Pre-Planned" Technology Insertion Route

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Summary

Parts obsolescence was affecting all Alenia products / programs so that we had to identify a robust strategy to prevent uncontrolled effects.

The design of products family has taken the obsolescence management issue as key, basic, requirement.

The basic ideas on the back of our pro-active approach for obsolescence issues are:

⇒ All products (in terms of equipment , subsystem or systems) design shall offers a flexible , open architeture which permits to change a specific functional block maintaining unchanged the overall architecture.

⇒ The "Open architecture" used shall facilitate any design changes into the defined functional blocks (caused by obsolescence issues) because of the high level of interface standardization.

⇒ A product configuration for a pre-determined period of time shall be maintained by performing components buy for all expected production batches including logistic support, allowance and spares.

⇒ There will be a defined periodic Product enhancement which permit a pre-planned obsolescence removal activities and relevant design changes.

⇒ There will be an high level of backward compatibility between the updated system configuration and the previous one.

⇒ Technologies which support the Product enhancement will be consolidated and introduced at a point where the level of risk is considered acceptable (or obsolescence became a major issue).

⇒ There will be a "synchronised technology insertion route" defined in the frame of the Company strategies which takes into account Customers requirement and market trend.

⇒ The obsolescence removal activity can't be "just in case" but need to be anticipated and synchronized with a new technology insertion phase and or a step for a product enhancement.

⇒ There is an absolute need for a company organization capable of provide continuos market survey so that any corrective action can be taken on time for a minor changes or a major, synchronised product upgrade change.

Paper presented at the RTO SCI Symposium on "Strategies to Mitigate Obsolescence in Defense Systems Using Commercial Components", held in Budapest, Hungary, 23-25 October 2000, and published in RTO MP-072.

BACKGROUND

Business and Products

Alenia Difesa UBSA is a branch of Finmeccanica (the major Italian company in the high-tech business) in charge of developing , producing and maintaining electronic equipments , subsystems and systems to be installed on fixed and rotary wings aircraft.

Since 60’s it is present in this business area having participated to the major European programs such as the Tornado and Eurofighter aircraft, the EH101 and NH90 helicopters .

The Alenia Difesa UBSA main products consist of Mission and Navigation computers, including the relevant Operational Flight Programs, Displays (Head-Up, Head-Down, Helmet) and all simulation and integration support systems required for development and maintenance of the on-board avionic systems.

Introduction

- Obsolescence is an industry wide problem: it is in general not new, however, the rate of component obsolescence is increasing rapidly since the beginning of the nineties.
- Military component manufacturers are consolidating and withdrawing as the world market reduces. The reasons for this development are to be found in the geopolitical changes of the nineties and the Perry Initiative. In 1992 over 72.000 Military devices were available - by 1998 this figure was 38.000, which means that approximately 50% of the active semiconductor devices available at the beginning of the program development phase could be discontinued by the industry.
- As the specification of standard components increases, the requirement for military components decreases. Today the market share for military semiconductors is less that 0.7% compared to 17 % in 1976 and 7.5% in 1986. The market situation of 1997 has become worse, and further manufacturers have discontinued their military production lines. .
- Component production live cycles are much shorter than the supported lives of military products.

Whereas the system life cycle of a military aircraft is over 50 years with clearly increasing tendency over the last decades (as shown in the table below),

Aircraft	In service since	Phase out (projected)	Useful life[1]
F15	1975	2010+	35 years
F14	1973	2010+	37 Years
F4	1972	2010	38 years
UH1	1959	2004	45 years
Tornado	1978	2030	52 years
KC 135	1957	2017	60 years
B52	1955	2040	85 years
EF2000	2001	-	-

the introduction rate for new microprocessors today is two years and new memory families are introduced at a rate of less than one year.
Moreover the introduction of new logic families with lower supply voltages will result in the obsolescence of the entire 5V technology within the next 5 years.

[1] These figures do not include the development phases of the A/C which also tend to increase considerably during the past decades

Definitions and abbreviations

Obsolete	A component which is no longer manufactured.
Obsolescent	A component which is declared to become obsolete by the manufacturer
Potential Obsolescence	The fact that components may still be active, however obsolescence is expected in the near future
Obsolescence	The process of becoming obsolete
Last Time Buy	Components procured to secure a series production or support programme after manufacturer has notified the end of production.
Life Time Buy	Purchase of the quantity of components predicted to be required for a defined period. Mainly used for risk items such as ASICS, connectors, memories, processors, etc.
Bulk Obsolescence	A large number of complex semiconductor and microcircuit devices on one SRI have become obsolete.
Life Cycle Code	Each active device have assigned a Life Cycle Code (ranging from 1 to 5) as follows:

1.	Introduction	The component (and relevant technology) has just been introduced
2.	Growth	The component (and relevant technology) has established a market position
3.	Maturity	The component (and relevant technology) has become industry standard
4.	Decline	The component (and relevant technology) is obsolescent and the probability of a manufacturer notification to become obsolete is very high
5.	Phase out	The component and relevant technology is obsolete

Tranche	Specified quantity of “product” (LRU/SRU) to be produced during a specific period of time

Abbreviations

A/C	=	Aircraft
ASIC	=	Application Specific Integrated Circuit
BoM	=	Bill of Material
DRL	=	Data Requirements List
EAPF	=	Engineering Alteration Proposal Form
ECR	=	Engineering Change Request
EF	=	Eurofighter
FFF	=	Form, Fit and Function
FMECA	=	Failure Modes Effects and Criticality Analysis
HW	=	HardWare
LCC	=	Life Cycle Code
LRI/U	=	Line Replaceable Item/Unit
LSA	=	Logistic Support Analysis
MTBD	=	Mean Time Between Defect
MTBF	=	Mean time Between Failure
OC	=	Obsolete Component(s)
OMP	=	Obsolescence Management Plan
PCB	=	Printed Circuit Board
PI	=	Production Investment
QML	=	Qualified Manufacturer List
QPL	=	Qualified Product List
RFQ	=	Request for Quotation
SP	=	Series Production
SRI	=	Shop Replaceable Item
STTE	=	Standard to Type Test Equipment
SW	=	SoftWare

Strategies

A Brief overview

Parts obsolescence was affecting all Alenia products / programs so that we had to identify a robust strategy to prevent uncontrolled effects.

First , we had to establish a company organization (Human resources , methodologies and tools) able to support a market survey activity , to provide an early warning information to the project/program management team , in order to decide a “cure” or a “corrective” action (i.e. design change, last time buy …).

Second, we have to live togheter with different products:

“old” products , still in production
“new” products , in development .

Old products

We were not in position to change “drammatically” their architecture.

Consequently we were only able to monitor the market and to apply the corrective actions when obsolescence issue arise (i.e. design changes “just in case” several last time buy for the batches still to be produced) by adopting the specific company organization and processes.

We considered this case as purely “passive” approach.

New Products

We have had the opportunity of “new” programs for which we had to build a completely new product family.
At the beginning we have perfomed a market analysis looking at the COTS (Commercial Of The Shelf) vendors of electronic modules/equipments (i.e. processor modules, chassis …) .

Initially use of COTS provided SRIs have been considered as a good option to manage obsolescence but, later on, we have decided to design our own product families since:

- the vendors of COTS modules meet with the same obsolescence problem,
- we are not in a position to control their products evolution because they are driven by different market (i.e. the commercial market),
- our system shall offer some specific capability (environment , performance) not available as COTS on the market,
- COTS module binding us on the “third” party for our business.

The design of such “new” products family has taken the obsolescence management issue as key, basic, requirement. We have been in position to establish a “pro-active” approach also considering that the parts obsolescence problem cannot be resolved once and for all: *sooner or later some parts became osbolete*.

Having in mind the products life cycle, we focused our attention on the fact that all products are affected by periodic upgrades, at least for the following basic reasons :

- it has to offer the best trade off between price and performance
- it has to follow the technology improvement trend and the relevant market

Products families

On the base of our previous experience, we have designed a state of the art product families based on:

- advanced design criteria (latest technology, software development tools,..)
- open architecture concepts with the adoption of “COTS” device families

that gives the most effective benefits with respect to the obsolescence issues.

Open architecture

Our basic view is that obsolescence can be controlled properly being capable of porting old technology into a new one by defining an Open Architecture on which the core components are under our direct control (Alenia design) or are managed with an adeguate level of supplier committment (key suppliers are involved directly in the Alenia Difesa product strategy).

We also have defined a deep level of functional standardization (HW & SW) which permits an easy , localized and well controlled (low risk) modification , in case obsolescence occours .

Several definitions and solutions are applicable in realising so-called *Open Architecture*.

In defining our “ interpretation” we have considered the following guidelines as “Basic” design requirement:

- the system architecture shall be modular and scalable
- it has to be based on the most diffused global and local HW interfaces
- it has to be logically organised in “layers” so that all the interfaces between different layers (HW & SW) shall be clearly identified
- the HW & SW layers shall have “standard” interfaces, where standard means
- “most diffused and supported on the market”

Therefore we have organized our open architecture by “clearly identify” the following :

a) functional blocks , over standardized local bus architectures:
the system architecture has been divided into functional blocks to make the HW layering easely interfaceable by the SW layers.

b) local bus networks:
PCI communication bus has been selected as it is the most suitable in terms of market availability and support (having dominant and recognised position in PC architectures)as well as it is offering optimal performance

c) global bus networks:
VME communication bus has been selected as the most suitable in terms of market availability and support also offering optimal performance

d) logical & physical interfaces (HW):
Using PCI and VME buses it has been possible to define FPGA/ASIC based communication “bridges” between functional blocks.
Logical protocol to have access on both sides of each functional block have been defined and standardised.
The functional block can be composed of discrete devices as well as contained into a single VLSI device (i.e. Hybrid , ASIC , FPGA)

e) API (Application SW to Basic Software) interfaces:
Our experience has demonstrated that software packages* development and certification in military systems, costs significantly more than hardware development and re-certification.

Therefore key target was to minimize impact of obsolescence on the software side by defining :

a) a robust , well proven, basic software to operational software logical interface, based on COTS operating systems .

b) a standard COTS OFP SW factories (i.e. VPI VAPS for graphics , ADA for OFP) .

*(Basic and Operational Software)

Design criteria
1. The Industrial Grade components quality level is largely used in all the Alenia Difesa modules . This increase the equivalent (pin to pin) component choices.

2. The HW modules have been designed with the key requirement of technology rationalisation (reduced amount of connector families , reduced set of device types..)

3. Modular approach to the sub-module has been encouraged to increase HW interface robustness.

4. Packaging optimisation has been performed

5. Rationalisation of component types and packages has been defined

6. Topology optimisation has been identified (specially for analog power design)

COTS devices in Alenia products

In designing Alenia products we have identified two different critical levels of devices:

a) *Key Components* : all those components for which remove obsolescence means larger HW re-design with significant impact on the SW (both Basic SW and Operational Flight Programs) already developed and certified.

b) *Low Level Components* : all those components for which remove obsolescence results in a “slight” HW modification possibly without impact on the existing SW

Key components have been selected considering the following factors :

- must be available inside the commercial market
- must have multiple suppliers
- shall comply with the most popular backplane buses or std interfaces
- shall be available at least in the “industrial quality level”

We have classified as Key Components :

a) **Processors** : specific contract have been defined with the main Processor suppliers (i.e. Thomson , Analog Devices…) in order to be guaranteed about component deliveries for all the Alenia Difesa programs.

b) **ASICs / FPGA** : this components have been developed in the VHDL language. This permit an easy “migration” of the embedded functions from an old technology to a new one supporting (if required) component replacement.

c) **CPLD / PLD / PAL** : this components have been programmed through a dedicated tools widely used on the market. This permit an easy “migration” from an old component technology to a new one.

d) **HYBRIDS** : specific contract have been defined with the main suppliers in order to be guaranteed about component deliveries for Alenia Difesa programs.

e) **RAM , EPROM , EEPROM** : We have identified as much as possible most diffused components on the market taking into account those devices with more that two sources and any potential growth in terms of addressing capability to permit an easy change in case obsolescence arise.

Company organisation and tools

Obsolescence Management requirements

The following list identifies just a few of the major contractual requirements recurring for the Obsolescence Management.

(a) Suppliers (as Alenia) are responsible for management of all types of obsolescence in order to fulfil their contractual obligations vs the Purchaser.

(b) Suppliers will make arrangements to ensure a common build standard is maintained throughout each production tranche in respect of obsolescence.

(c) There will be a phase prior to the commencement of each production tranche to prepare for a common Build Standard for that tranche. This Build Standard shall be agreed with the Purchaser.

(e) Interchangeability at module level shall be maintaned troughout a production tranche, with no effect to the customer technical publications or in-service maintainability.

(f) Any Customer/Purchaser change requests opportunity shall be taken to concurrently address any sensible and practicable associated obsolescence changes.

The above requirements are satisfied having a specific Parts Management System responsible of:

1) Removal of all existing and potential obsolescence prior to commencement of any Series Production.
2) Management of all further obsolescence occurring during Series Production

Contractual situations

Two different contractual situations are requested to Alenia Difesa to distinguish in order to manage, to discover and to monitor the surge of the obsolescence in any LRU design:

- *Existing Contracts*
- *New Contracts*

Existing Contracts

For the existing contracts is required to perform the following activities:

a. To maintain the existing contract conditions and to acquire the components with the same Standard shown in the relevant Part List.
b. To detect completely and exhaustively the components obsolescence at the initial stage of the design to avoid expensive redesign and re-qualification activities.
c. To monitor correctly the Obsolescence taking into consideration all the available options in order to reduce the impact, saving time and costs.
d. To take into consideration the impact of the quality level of the component selected during redesign and/or re-qualification activities if necessary

New Contracts

For the New Contracts is required to perform the activities covering the following aspects :

a. Obsolescence Free Degree (Obsolescence tolerance)
b. Quality Aspects
c. Equipment Manufacturing Process (Process Control)

Summarising for the New Contracts is required to produce a Parts Management Plan, linked to the Obsolescence Management Plan which reflect the adopted policy to support the contractual requirements for the useful life of the equipment.

Alenia Organisation

The organisation, management and responsability of the activities for the achievement of the Obsolescence Requirements is delegated to the Parts and Obsolescence Management Function inside of the Alenia RMT/LSA Department.
In particular the Obsolescence activities are managed and performed by the personnel of the above mentioned function with the co-operation of the Department involved in all the stage of project.
The engineers appointed to the Obsolescence tasks shall have access to the design data and drawings as required. They will be involved in the Project Design Review meetings as appropriate to cover the Obsolescence aspects and shall be informed of all proposed design changes.
The assessment regarding Obsolescence and Reliability implication shall be taken into account prior any decision on the implementation of design changes.
The Obsolescence Focal Point will interface with other disciplines correlated with LRI Project. Obsolescence information will be supplied to Reliability and Maintainability engineers for use in RMT and Logistic Support Analyses.
Close contact will be maintained with other Engineering disciplines (e.g. Design, Manufacturing, Purchasing) and Program Management to evaluate the impact of Obsolescence issues.

This Focal Point is responsible to co-ordinate all activities related to the Obsolescence within the Alenia Difesa and its Work-Share Partners.

An inter-disciplinary Obsolescence Work-Team is established.

The members of the team are members of all involved departments such as:

- Component Engineering
- Procurement
- Design Engineering
- Project Manager
- Manufacturing
- Program Manager

The Obsolescence Work-Team is responsible for fact finding and decision making in critical obsolescence situations.

Design criteria applied to minimise obsolescence impact

To minimise the impacts of the obsolescence, the following criteria shall be considered during design and development phase :

1. Emphasis shall be placed on the use of components for which multiple sources exist
2. Where possible all components shall be selected from preferred part list as Qualified Part List and Approved Component Database
3. Use of standard independent development environment

Solutions to deal with Identified Obsolescence

Depending on the on the LRIs “Obsolescence Health” the optimal strategies, recovery actions and solutions may differ.

Solutions may be classified as follows :

No.	Strategy	Description	Application
1	FFF equivalent	Replacement by a form, fit, function component	Multi source component, change to different source, no real obsolescence, problems may occur If the same quality level is unprocurable a substitution shall be activate.
2	Life Time Buy	All components for the series production programme (including spares and repair stock) will be purchased at the start of production	High risk is present when a single source supplier is considered in the relevant Part List (typical for ASICs and Hybrids). This solution is to be avoided when possible, it can be applicable when a specific batch of items are in production and their life cycle is well known and agreed.
3	Last Time Buy	Upon obsolescence notification by the supplier, a purchase of components is initiated to cover all future demand for the programme including spares and repairs.	This solution is applicable to a mature equipment and on isolated events only, but not for new design/re-design. It is also acceptable only if all obsolete components on a module can be removed by last time buys, otherwise a re-design shall be considered.
4	Substitution	Replacement by a part with acceptable non-compliance	This solution is applicable when no alternative components are present and a deviation can be accepted by the Customer/Purchaser. No re-design activities shall be considered.
5	After-market Supplier	Purchase from a Supplier who has purchased the rights and facilities to continue to manufacture the part from the original Manufacturer.	This is applicable to a mature equipment and on isolated events only, but not for new design/re-design.
6	Emulation / Cloning	FFF redesign of the obsolete component using current technology	This is applicable to the ASICs and other Custom designed components as Hybrids
7	Redesign	Re-design of the entire module to replace obsolete components with current technology. Major objective is to remove and avoid future obsolescence.	This is applicable when bulk obsolescence can be predicted or when at the beginning of a new tranche the rules are out of last time buys conditions
8	Inventory Survey	Use of internet tools (such as TACTech's Lo-K-tor) to locate components, which have become obsolete and which are for sale as excess inventory	This is applicable when the LRUs/SRUs are out of production but still in service (last phases of the life cycle of the equipment).

Obsolescence Activities prior the Series Production

The obsolescence activities to be performed prior to the Series Production shall be:

1. Obsolescence Survey
2. Status Assessment
3. Risk Analysis
4. Removal of Identified Obsolescence

Obsolescence Survey

Alenia Difesa maintain a Parts Management System which allows to identify, to report and to monitor the status of actual and potential obsolescence arisings.
The purpose of the Obsolescence Survey is to perform on each LRI the following activities :

a) Active monitoring of component obsolescence status performed by the responsible organisational entity, according to a phase model, in order to identify components that are approaching the end of their life cycle.
The phase model classifies components according to their Life Cycle Code

b) Assigning and updating the obsolescence status code to all components based on the monitoring described under a)

c) Maintaining a stock management policy to decide on life time buy, last time buy and design-out point, involving consideration of costs, alternate sources, lead-time and buy opportunity.

d) Planning of replacement/re-design activities including the assessment of alternative technical solutions and the associated risk. Sufficient buffer stock will be built up to avoid production schedules being compromised by re-design and qualification activities.
This activity includes notification to the Purchaser as well as to all Work-Share Partners involved.

Awareness of actual or impending obsolescence problems arises from a variety of sources.
These incudes :

- Manufacturers and Suppliers Last Time Buy Notifications
- Direct inquiries at the Supplier/Manufacturer
- Manufacturers Web Sites by Internet Tools
- Notification by Consortium Partners
- TacTech Look-up tool and TACTRAC tool (in use in Alenia Difesa from the middle of 1999).

Inside of RMT/LSA Department, the Component Engineer will update quarterly the obsolescence status of all LRIs active components by using TACTRAC System and will communicate to the Project Manager and Project Leader the obsolescence status, alerts and obsolescence projections of the last design Components Part List.
The result of the obsolescence survey will be included on a Quarterly Obsolescence Report that, for each component used within the LRI, will report as a minimum the following information :

a. Module Identification
b. Alenia Difesa configuration part number (as foreseen by the internal Codification Specification System and Component Part List)
c. Manufacturer commercial P/N
d. Manufacturer Name
e. Total quantity used on the SRU
f. Life Cycle Code as foreseen by TACTRAC tool
g. Component estimated years until unprocurable
h. Component estimated years until obsolete
i. Source of the information
j. Sourcing Status
k. Obsolescence Status Assessment
l. Recommended replacement of the affected components including the availability of equivalent components and their specification

Status Assessment

Assessment of all components of the LRI to identify known and/or expected obsolescence during series production is performed.
Basing on criticality and expected consequences, all the obsolescence cases are classified into 4 groups as follows :

		criticality
1.	Replacement available, same footprint	**low**
2.	Replacement available, different footprint(new layout is required)	**medium**
3.	No direct replacement available, different functionality • Design modification required • New layout • Software changes could be required	**high**
4.	No direct replacement available, process/technology obsolete (ASICs) • New component design • Module redesign • New layout • Software	**highest**

This classification is used to indicate and track the obsolescence criticality and risk in the “Obsolescence Report” for any specific program.

Risk Analysis

There are several structured reports available on the TACTRAC Reports Menu that Alenia Difesa use to perform a Risk Analysis. They are :

- **System Life Cycle Matrix Report**
  The Life Cycle Matrix report displays information that shows where the part(s) in the selected system scope falls into Average Life Cycle. When assessing the heath of a system, looking at the parts that fall in the Introduction, Decline and Phase Out phases, these are the components with potential reliability or procurability problems that need solutions.

- **Source Depth by Product Type Report**
  The Source Dept by product Type Report breaks out the selected scope by part family (Diode, Interface, etc.) and Manufacturer. For the family and each Manufacturer, the report shows how many parts of that family the Manufacturer can actilvely supply in the selected system scope, according to the approved family/recommended replacements. This report displays the number of parts available for each part type from the manufacturer indicating also which manufacturers you may be able to obtain better price from.

- **Potential Sourcing Issue**
  The Potential Sourcing Issue Report displays all parts that currently have, or could shortly have, a problem with Manufacturer availability according to a specific selected filter.
  The reports displays parts if they fall into any of the following categories according to the filter criteria:

➢ **No Source- Obsolete** means the part and its recommended replacements have no active sources of supply
➢ **No Source-Unprocurable** means the part has no active sources of supply but at least one of its replacement does have active source of supply
➢ **Single Source-Unprocurable** means the parts has no active sources of supply and its replacements have only one active source of supply
➢ **Single Source-Procurable** means the part has only a single source of supply
➢ **Life Buy** means the part is under Life Time Buy status and will no longer be available in a short period of time
➢ **Inactive for New Design** means the part has been determined by DSCC to not recommended for new design

- **Active Alternates List by Quality**
  The Active Alternates List by Quality Report displays any active alternates from parts based on the filter for parts in the Selected System Scope broken down by Quality Level. With this report is possible to see which parts in the system have the most alternatives and how many alternatives exist at each Quality Level.

- **Active Alternates List**
  The Active Alternates List Report displays the number of active and inactive alternatives for parts selected by system scope. To assess the health of the system, it is necessary to look at the usage in the system in relation to the number of active and inactive alternatives.

These reports are very useful in gauging any potential risk in supporting the System from an obsolescence and manufacturer availability standpoint.
Alenia Difesa uses these TACTRAC facilities to perform Risk Analysis for the LRIs.

Removal of Identified Obsolescence

All the identified obsolescence reported on the LRI Quarterly Obsolescence Report shall require a recovery action. The recovery actions may be several as follows:

a) **Replace the obsolete component by replacement/redesign activities.**

The replacement/redesign activities for replace obsolescent components shall maintain unchanged the original interface at LRU/SRU level in accordance with the interface specification.
For the above, the interchangeability at Form, Fit and Function (FFF) level of the previous version of SRU with the new version will be guaranteed.
The new component selection, selected to replace the obsolescent one, shall be determined taking into account the following characteristics:

- Clear technological longevity and maturity
- Multiple Sources
- Market position

When alternative components have been identified they will be included into Quarterly Obsolescence Report with the following information:

1. The commercial p/n and Manufacturer name.
   When the alternative component is a multiple source, the commercial p/n and name of each Manufacturer shall be reported.

2. Which obsolete component will be replaced by the new one

3. The compatibility level respect the component to be replaced as:
- Pin to Pin compatible
- Function compatibility
- Not full compatible

When not full compatible, the redesign at SRU level will be analysed in more details taking into account the practices to be adopted in using the new component and relevant technology.
This process captures the logic of Large Scale Integration microcircuits such as microprocessors, microcontrollers, arithmetic logic units, PALs, FPGAs, EPLDs etc. In that cases the Quarterly Obsolescence Report will be updated including all the components that have been impacted.

4. The impact on the qualification status of the LRI

5. The Status level of the new components including :

- Multiple Sources
- Technological maturity
- Adequate Life Cycle Code

b) **Provide a Last Time Buy action**

When a Last Time Buy action is considered then the future requirements will be estimated and the total buy cost calculated. Holding costs will be included in the cost estimates. Since Last Time Buys are time limited the response time to implement will be the shortest and the relevant due date will be reported and timely controlled.
Where a Last Time Buys are employed, a procedure will be developed to control the long-term storage, life refresh and health of the component or die.
After that the latest date of the Last Time Buy has been verified, the quantity to supply will consider:

- The quantity to support the Production Investments (PI)
- The quantity to support the Series Production phase

c) **Procure Obsolete Components**

When a component have become obsolete, procurement of such part could be achieved by After-Marked Suppliers from stocks or other searching methods.

d) **Life Time Buy of Critical components**

For components which have been identified as being critical the following conditions shall be verified:

1. The latest date of the Last Time Buy
2. The quantity of components required to :

- Support the Series Production
- Support activities to protect the relevant LRI program

Documentation and Data Requirements List (DRL)

Design documentation and DRLs updating required as a result of re-design activities shall be defined in the respective EAPF.

Obsolescence Management during Series Production

Approaches

Reactive Approach

The reactive approach deals with obsolescence upon occurrence. It makes no specific provisions for obsolescence which may occur in the future. However, obsolescence may occur and will upon occurrence raise cost. This approach constitutes a high risk on the side of the Purchaser, because the impact of future obsolescence is not known and a budget cannot be set aside.

Proactive Approach

The Proactive approach is similar to an insurance policy and its objective is to reduce the costs in managing the LRI Unit. For the above Alenia Difesa offers insurance against obsolescence.
The Alenia Difesa Obsolescence Management is based on the proactive approach.
Alenia Difesa IQB0426 internal procedure defines the process and procedure which shall be used to monitor the obsolescence status.
The obsolescence activities to be performed during the specific LRI Series Production shall be:

⇒ Obsolescence Monitoring
⇒ Corrective Actions
⇒ Risk Analysis

Anticipated Extent of future Component Obsolescence

Assessment of the development phase results of the existing design identifies all components that are already obsolete or will become obsolete shortly.
A prediction of the non availability of components can only be based on known technology and market trends.
Such prediction of the ”health status” are based on the Life Cycle Codes (LCCs) and relevant availability in terms of **“In Production”** or **“Not in Production”** data of components with respect to obsolescence.
These component LCCs are associated with the their anticipated family type life span.
As described in section 1.5 the LCCs are provided by the TACTRAC system of TACTech database.
This online and real time Obsolescence Management Tool provides on request a preview of the Health Status of an SRU such as a PCB for the life span of the LRI or any other time span.

Obsolescence Monitoring

If potential obsolescence becomes known fairly in advance, the necessary measures may be taken, and major problems can be avoided at an acceptable cost level.
The objective is therefore to conduct “Proactive Obsolescence Management” as opposed to “Reactive Obsolescence Management” .
Obsolescence Monitoring activities shall be carried out during Series Production to establish the obsolescence status of the LRI and relevant SRUs.
In the following sections are described the facilities which will be used to perform this task.

TACTech Database

Tactech database provides information on the component status.The information consists on an indication of where the component function and related technology is in its lifecycle and what alternatives are available including information relevant to direct replacements down to commercial or industrial grade equivalents.

Commercial database

When a component has become obsolete and why it has become obsolete no consistent and complete database is available at Alenia Difesa. In these cases a lot of Commercial database on WEB Sites are available and consultable to determine the obsolescence status and availability of the component under analysis.
This kind of information will be managed and filed by the Obsolescence Focal Point within Alenia Difesa.

Manufacturer Notification

In most cases the obsolescence is detected when procurement is required. This occurs for those items purchased in small quantities from distributors and Alenia Difesa just receives a notification that the component in question will become obsolete and a Last Time Buy frequently is offered.
Alenia Difesa is strongly avoiding this kind of notification as a reactive approach sensitising continuously the Manufacturers in giving these information as a proactive approach.
However this kind of information will be managed and filed by the Obsolescence Focal Point within Alenia Difesa.

TACTRAC Tool

TACTRAC tool will be used during the LRI Series Production as a support tool for obsolescence management.
It is also noted, that various European Companies involved in EF2000 Programs have already subscribed to TACTRAC and are using the service successfully.
Alenia Difesa is using the TACTRAC tool (installed in April 1999). The system is based on a component data base which is kept current by the service provider.

The main TACTRAC features are:

(1) **Constant electronic monitoring** of BoMs with real-time discontinuance notification. All areas of procurement vulnerability in a bill of material are automatically identified and prioritised. A full analysis of sourcing depth is provided and areas of sourcing vulnerability are identified. Furthermore the system provides immediate notification alerts on military microcircuit discontinuance and automatically notifies the user if any sourcing change occurs in the bill of material be it a new source or loss of a source.

(2) **Automated real time electronic (living) library** of semiconductor availability
The component library provided contains virtually all known military microcircuits as well as their industrial and commercial grade equivalents. This library is constantly updated with information received directly from all QPL/QML manufacturers.
Detailed parametric data are available on all of the approximately 200.000 individual devices in TACTech database.

(3) **Identification of critical items** such as LRUs, SRUs, ASICs and components driving obsolescence.

(4) **Life Cycle modelling** at both the component and configuration level.
Preventive obsolescence management involves component selection and equipment level analysis, that takes into consideration component life cycles. Based on the technology attributes of the device being assessed, life cycles are calculated and maintained for each device in a “living library”.

(5) **Real time component procurability monitoring**

(6) **Procurement problem identification** with solution alternatives.

(7) **Automated data retrieval** and analysis techniques for determination of the best possible solution.

(8) **Configuration management** flexibility to analyse a single SRU or to roll up multiple system or program combinations.

(9) **Automatic Indenturing capability** to identify discontinuance impacts at the component, LRU and SRU.

(10) **Cross reference** of all military microcircuits to industrial and commercial grade equivalents. All military semiconductor devices as well as all cross reference equivalents reside within the library. This allows to identify all FFF equivalent parts in descending order of quality.

(11) **Parametric part search** capabilities
In selecting a device for a particular application, an appropriate part can be selected without knowledge of the manufacturer’s part number. The system allows the user to identify the part by key parameters only for parametric searches. All parts meeting the input criteria are identified in complete technical detail inclusive of life cycles and sourcing availability.

(12) **Access to an electronic marketplace** for hard to find components

(13) **Data sharing** among linked users on corporate level (or within other structures) to enable co-ordinated decisions and cost sharing and to avoid task redundancy

Corrective Actions
The information obtained from Obsolescence Monitoring shall be used to perform the recovery actions to be reported in the updated Quarterly Obsolescence Report.

Conclusion

The basic ideas on the back of our pro-active approach are:

⇒ The products (in terms of equipment , subsystem or systems) design shall offers a flexible , open architeture which permits to change a specific functional block maintainig unchanged the overall architecture.

⇒ The Open architecture shall facilitate any design changes into the defined functional blocks (caused by obsolescence issues) because of the high level of interface standardization. The product design shall be so open and modular to permit changes and update with a reasonable level of risk and cost.

⇒ A product configuration for a pre-determined period of time shall be maintained by performing components buy (at least for the key components) for all expected production batches including logistic support, allowance and spares. During that period, the Customer shall be guaranteed by Alenia Difesa against any obsolescence issue by applying a “Last Time Buy per Batch” policy and equipment re-design, where necessary (minor changes due to “low critical level components” obsolescence).

⇒ There will be a periodic Product enhancement (Production Batch by Production Batch) which also permit a pre-planned obsolescence removal activities with relevant design changes.

⇒ There will be an high level of backward compatibility between the new , updated , system configuration and the previous one . The Customer is taken aware about any difference by using a very efficient and transparent configuration control system.

⇒ Technologies which support the Product enhancement will be consolidated and introduced at a point where the level of risk is considered acceptable or obsolescence became a major issue.

⇒ There will be a “synchronised technology insertion route” defined in the frame of the Company strategies which takes into account Customers requirement and market trend.

⇒ The problem of parts obsolescence can’t be solved as a one shot event . It’s control and management has to be considered as an essential requirement for an high quality product.

⇒ The obsolescence removal activity can’t be “just in case” but need to be anticipated and synchronized with a new technology insertion phase and or a step for a product enhancement.

⇒ There is an absolute need for a company organization capable of provide continuos market survey so that any corrective action can be taken on time for a minor changes or a major , synchronised product upgrade change.

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Generic Tools and Methods for Obsolescence Control

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Summary

The increasing discrepancy between the life cycles of professional electronics equipment and the life cycles of the components (which are largely intended for volume markets) means that professional electronics manufacturers must implement methods, processes and tools to give their customers long-term availability guarantees for their products despite obsolescence problems in the components.

Although this effort must be made at the level of each unit and adapted to the type of product, the customers' needs and internal organisation, the existence of common methodological tools and principles can significantly help each unit set up the appropriate procedure for their particular case.

This paper gives an overview of the methods and tools set up within the Thomson-CSF group to support the units in this procedure.

These can be split into four levels, which correspond to increasing maturity of the obsolescence risk control.

Level 1 : curative level (during production and use phases).

Level 2 : downstream preventive level (also during production and use phases).

Level 3 : upstream preventive level (during development phase).

Level 4 : upstream preventive level (during design phase).

Finally, it asserts that controlling obsolescence and being able to guarantee the long-term availability of equipment is now a major part of the professional electronics manufacturer's job, and is an increasingly important factor in meeting customers' needs.

1. An irreversible change requires a response

The problem of obsolescence suddenly took on significant proportions during 1993 and 1994. In reality, it is a much older phenomenon (it has always existed right from the origin of the components). However, up to 1993-1994, the professional electronics world (manufacturers and customers) let itself think that it was a minor problem that could be solved easily in production centres by replacing the obsolescent component by another functionally equivalent component.

Three events, the effects of which came together in 1993-1994, significantly increased the scale of the phenomenon and the seriousness of its consequences, and gave rise to a radical questioning of the processing methods previously used. These three events were:

1) the gradual loss of influence, on the semiconductors market, of long-cycle professional electronics industries (aerospace, space, defence, industrial control) in favour of short-cycle consumer industries (computer, telecommunications, multimedia). Below the crucial 10% threshold, the long-cycle industries were no longer an attractive outlet for the semiconductors industry, which was seeing an explosion in its market (+20% per year);
2) the DoD's announcement of its intention to promote the use of dual-use technologies (see [1]) wherever possible and, consequently, in the field of components, to target its aid on absolutely vital components in defence equipment. Several semiconductor manufacturers then decided to stop producing MIL-883 components. As regards quality, this move was judicious as the absence of these components today does not prevent the design of equipment that is just as reliable as before. However, as regards long-term availability, it means that manufacturers have to work with components that do not have the same durability as those that were formerly intended for the long-cycle industries;
3) the considerable developments in technology that meant that, for the first time in 1993-1994, obsolescence affected components that were:
   - difficult to replace (no upward compatibility),
   - difficult to emulate with an ASIC (as they were already very complex),
   - and had an impact on numerous software lines (i.e.: microprocessors).

These three events are permanent, not to mention irreversible.

The professional electronics industry could therefore no longer continue to treat the obsolescence phenomenon as a minor problem. It had to organise itself to take the appropriate steps to reduce the consequences to a minimum (as no-one has yet found a miracle solution to end the phenomenon of obsolescence or completely eliminate its consequences).

Paper presented at the RTO SCI Symposium on "Strategies to Mitigate Obsolescence in Defense Systems Using Commercial Components", held in Budapest, Hungary, 23-25 October 2000, and published in RTO MP-072.

2. The analysis of the situation carried out at Thomson-CSF

2.1 Working groups

By 1995 it was clear that this change was irreversible, and to find the most appropriate response to it, the Thomson-CSF group set up two working groups with representatives from all of the units affected, for various reasons, by the problem of obsolescence.

- The first was in charge of analysing the short-term responses (mainly curative) to the problem of obsolescence.
- The second was in charge of analysing the preventive measures to be put in place over the whole life cycle of a product in order to reduce the consequences of obsolescence problems to a minimum.

These groups operated during 1995 and 1996. Their recommendations were implemented very quickly and make up the anti-obsolescence system currently used within Thomson-CSF. These groups now meet two to four times a year to re-analyse the situation and the appropriateness and smooth operation of the system.

The existence of these groups allowed for plentiful exchanges between the units represented, both on the problems encountered and on the best practice implemented to remedy them. Their main conclusions are set out below:

2.2 The problem must be dealt with by the manufacturer

The first element that appeared in the working groups was the diversity of customers' attitudes to the obsolescence problem.

The Thomson-CSF group (and therefore the units represented in the working groups) operates on three main professional electronics markets:

- the defence sector,
- the aerospace sector,
- the Business to Business or B to B sector.

This position allowed it to note that customers behave in radically different ways when faced with obsolescence and that this behaviour causes equally antagonistic reactions from the manufacturers.

On one hand, customers in the civil aviation sector (aircraft manufacturers, airlines or airports) and B to B sector customers feel that it is up to the manufacturer to find solutions to the obsolescence problem and wish to distance themselves from it as far as possible.

On the other hand, in the defence sector, several MoDs in large countries (particularly, but not only, the US DoD) wanted to find solutions to the obsolescence problem and pass them on to their manufacturers.

This second attitude is a sort of extension of the old situation when the MoDs (and especially the DoD) were major suppliers of technology in the field of components. However, in the new situation, it inevitably affects costs optimization, as sharing responsibilities between the manufacturer and the customer does not facilitate the search for an overall optimised solution to the obsolescence problem. Rather, it encourages the implementation of radical but costly solutions (strategic stocks, financing of the component manufacturer, setting up of alternative sources, etc.) when very often the problem could be solved at a lower cost within the framework of a more general approach (as several components are often simultaneously affected by obsolescence).

This attitude leads to a lack of competitiveness for the manufacturer, who has to manage two conflicting processes depending on which market it is dealing with.

Everything points towards the idea that this specific feature of the domestic defence market will gradually disappear. The defence market has already admitted, several years ago, that it could cover 90% of its requirements with components designed for other markets. It is probable that sooner or later it will also decide to delegate responsibility for controlling the risks linked to these components to the manufacturer, as other professional electronics customers do already.

For all these reasons, it was apparent that the Thomson-CSF group should equip itself with means (tools and methods) to allow it to offer all its customers, including those in the defence sector, solutions in which it would take on the obsolescence control itself. Of course, this does not exclude dialogue with the customer to inform them of the problems encountered and try to find the most appropriate responses with them. Such dialogue is even strongly encouraged (see § 4.1). Nor does it exclude working differently on some contracts, with customers who want to be more closely involved in the search for solutions to obsolescence.

There is now a wide consensus of approval for this process in France, including in the defence sector; the French MoD and the defence manufacturers are on the point of entering into an agreement at the end of which the MoD will hand over most obsolescence problem control to the manufacturers and even, more generally, most of the control of problems linked to components (selection, obsolescence, quality, reliability, resistance to environment, etc.).

This procedure falls within the same logic as that used by Thomson-CSF and the French MoD in the area of component quality. In 1988, the decision was taken to switch to commercial and industrial components to replace military components (see [2]). This began with radio equipment for the French army. Gradually, this strategy spread to all the equipment produced by Thomson-CSF in all areas (aerospace, defence, B to B), and today the Thomson-CSF group uses very few military range components or QML certified components on new designs. The group itself provides quality assurance using a very strict method of assessing component processes (see [3]). This yields a considerable saving on components costs, and also much better control of quality and reliability in severe environments (see [4]).

The only limit that must be placed on this procedure relates to components with specific defence uses. These are components necessary in the defence area (as their specific performance has a direct impact on the performance of the

defence systems) but for which the non-defence market is too small to ensure the financing of the necessary processes. A typical example is high power GaAs. For reasons that will not be elaborated on here (see [4]), it is often difficult for the manufacturer to provide this financing. Government aid may be necessary to provide the financing and prevent supply shortages that would cause insurmountable industrial problems. Again, however, the procedure must be to limit these processes to those that are strictly necessary, so that this procedure is the exception and not the rule. Moreover, this is what is recommended in Secretary Perry's Memorandum (see [1]).

2.3 The procedure must cover the whole life cycle

The second element that the working groups agreed on unanimously was the need to take obsolescence into account and to seek to provide the best responses at every stage of the life cycle.

Of course, the first question that comes to mind in a discussion about obsolescence is to find out which solutions are applied to it (i.e. once the problem has occurred).

This is an important subject, and any good anti-obsolescence system should provide a response to it. We will therefore deal with this subject in §3.1 and 4.3.

However, limiting oneself to purely curative treatment, once the problem has arisen, is certainly not the best way to approach obsolescence.

In fact, in addition to the curative approach that applies to the phases of production of the equipment and its use by the customer (including logistic support), the obsolescence problem must be analysed constantly at each stage of the life cycle with the aim of setting out the best solution at each stage, i.e. the solution that will minimise the consequences of obsolescence in future. This preventive attitude of systematic risk anticipation and searching for the best solutions applies to:

- the production and customer use phase (see §3.2 and 4.3),
- the development phase, particularly for component selection (see §3.3),
- the design phase, particularly for architecture selection (see §3.4 and 4.2),
- and even the pre-sales phase, as the establishment of sound and explicit contractual rules between the manufacturer and the customer is such a vital element to prevent any subsequent misunderstanding and confusion (see §4.1.2).

2.4 The variety of situations and appropriate responses

The third element on which everybody agreed was the great variety of situations and consequently the difficulty of transposing best practice as it is from one unit to another when the situations are too different.

As a rule, for each situation, the selection of the most suitable response must take into account:

- the customer's needs. The range of applicable solutions would therefore be very small if the customer required all its equipment to be strictly identical. The range would be larger if the customer were satisfied with functional equivalence (fit, form, function). It would be even larger if the customer looked favourably on progressive updates to the equipment in order to benefit from technological developments (enhanced performance at a lower cost);
- the quantities to be provided and the interval between the provision of these quantities; the best response will not be the same, depending on whether it is:
    - a delivery to be made within a short deadline (≤ 2 years),
    - a large quantity to be delivered within a long deadline,
    - a small quantity to be delivered within a long deadline;
- the "commonality" between products. In some situations, a policy of designing from modules common to several products can allow for better optimised responses than would have been possible if each product had been considered in isolation;
- etc.

2.5 Use of common tools and principles for obsolescence control

As they were unable to define best practice applicable to everyone in all situations, the participants of the two working groups rapidly agreed unanimously on the benefit of pooling their experience and defining a set of common principles and setting up the corresponding tools.

More specifically, they came up with the following analysis:

1) a fundamental approach in obsolescence control is to tackle the problem in terms of risk control;
2) risk control can be broken down into a few simple principles (list of questions to ask oneself). These principles can be common to everyone, even if the responses to them (best practices) vary depending on the individual situation;
3) risk control requires certain tools that also gain by being common to everyone;
4) in addition to the principles (theoretical), a collection of best practice can be very useful for everyone (benchmark type approach), even if it is not always easy to transpose a given best practice from one situation to another.

This analysis allowed the groups to design a system that was common to all of the units in the group. The system has now been in operation for several years, and will be described in this paper.

However, we will only touch briefly on the best practices implemented in the units, as they are often linked to a specific context and we wish to focus on points common to everybody in this paper. Other papers (particularly [5], which illustrates the procedure recommended in §4.2.1), give a clearer idea of what these best practices might be.

2.6 The common obsolescence control system

This system is illustrated in figure 1.

As we have just seen, it is made up of:

- a (common) tools section, supplemented by the availability of expertise,
- a (common) methods section, supplemented by an organisation in charge of coordination.

It covers every stage of the life cycle; the need for this was outlined in §2.3. It can be read from top to bottom, in chronological order of the life cycle, or in the opposite direction, in increasing order of maturity, as it is true that the most mature responses are those that anticipate the problem as far upstream as possible.

We will now describe it in more detail. We will begin with the tools aspect, which is easier to approach first as it gives concrete responses to specific problems. The tool aspect will be covered in chapter 3. We will then deal with the methods aspect, which is in essence more abstract, in chapter 4.

system → / ↓ phase	Challenge posed to products and contracts	Common expertise and tools	Common principles and methods
Preventive Upstream (design)	Design an architecture to - control obsolescence - permit upgradeability	Technoprice Incremental design	Thomson-CSF baseline: Methodologies, guides, documents CET's + TTM Coordination of all actions
Preventive Upstream (development)	Select components with maximum long-term availability guarantees	PPL Part list reviews	
Preventive (production, use)	Anticipate obsolescence Schedule redesigns to coordinate corrective action	Technolife Part list analysis	
Curative (production, use)	Be informed of problems in due time Take corrective action in due time	Warning system TCIS Obsolescence Task force	

Life cycle

Level of maturity

Figure 1 : Common obsolescence control system

3. Common obsolescence control tools in use in Thomson-CSF

Sticking to our philosophy of giving first a description of the precise responses given to the most concrete problems, we will describe the tools part of the common system in an "upstream order" through the life cycle of equipment. This will enable us to describe the means put in place to find solutions when problems are urgent, generally during the phases of production or customer use of the equipment. We will then examine what can be done in a more preventive (and more mature!) way by trying to anticipate problems, firstly during the phases of production or customer use, and then – better still – during the upstream phases of the life cycle, design and development.

3.1 The tools and expertise for curative treatment

The tools and expertise for curative treatment meet two aims:

1) to allow the units to be informed of problems in due time,
2) to allow the units to take corrective action in due time.

3.1.1 Being informed of problems in due time

Although it may initially seem surprising, the first obstacle to overcome to set up an effective curative treatment process for obsolescence is having the necessary information in due time.

From the component suppliers' point of view, the main characteristic of the professional electronics industries is that they give small orders spread over long periods. The suppliers do not therefore always automatically think of informing a "small customer" about all obsolescence, in particular when it occurs in components that the "small customer" hasn't ordered for months (sometimes years), or has never ordered before. Using sub-contractors for production only aggravates the problem as it creates yet another link in the information chain, with all the risks involved.

During 1993 to 1995, each Thomson-CSF unit had gradually set up its own obsolescence information gathering and processing department. However, this was costly and inefficient in terms of cover.

The decision was therefore taken in 1995 to give a support unit, TTM (Thomson-CSF Technologies and Methods), responsibility for collecting and processing all the obsolescence information and distributing it to all of the units in the group.

The initial principle was to ask every purchaser who was aware of an obsolescence problem to inform TTM, which would then immediately pass the information on to all of the units. In reality today, the information gathered by TTM comes mainly from relationships established with manufacturers and a systematic analysis of their web sites and of independent specialist obsolescence web sites. The purchasers now only provide additional information that, above all, highlights any deficiencies in the cover or reactivity of the system.

As shown in figure 2, the system actually goes well beyond simply distributing the information received:

First, the information gathered is processed. This work gives considerable added value in relation to the raw information, which is often:

- redundant (several suppliers announce the same measures),
- inconsistent (some obsolescence is a stoppage at the distributor, but the products still exist elsewhere),
- non-specific (a supplier announces that a family is no longer produced, without specifying an exact list of the parts affected);

Then, the components in question are matched with the Thomson-CSF component information system, which allows the units to identify them easily in their item databases. This also gives an initial list of potential replacement components.

When the file created in this way is distributed (once a fortnight), the units are asked in return to indicate which components affect them.

Thanks to this return of information, 2 additional services can be provided:

- firstly, an additional equivalents search (complete or approximate) is systematically initiated and the information obtained is systematically checked: when a component goes out of production, it is often the market that has disappeared and it is therefore useful to check that the equivalents have not also gone out of production;
- secondly, each unit also receives a list of the other units with the same problem, which is very useful for helping each other or looking for solutions together (stock, after market, substitute ASIC or PLD, etc.);

Finally, the information is archived in the Thomson-CSF Component Information System (TCIS) so that it can be found again later.

Today, this system is fully operational and every unit receives a file once a fortnight containing all the obsolescence detected over the last two weeks. The widely held opinion is that the coverage is very good.

Obsolescence warnings were given in this way for 20,000 components in 1999. The responses provided in return by the units show that, statistically, 10% of these components (2,000 per year) have an impact on at least one unit in the group.

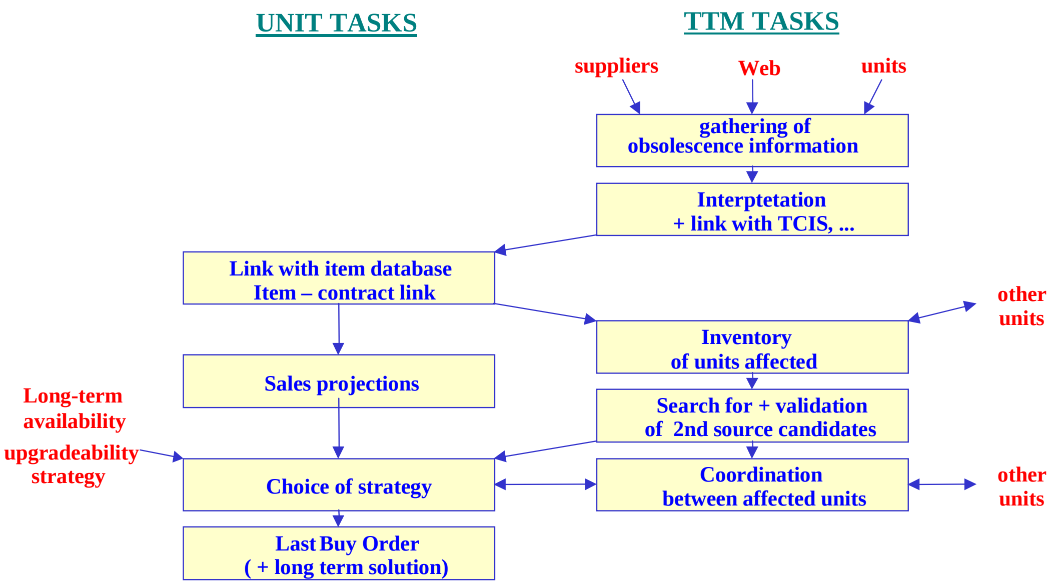


Figure 2 : Obsolescence warning system

3.1.2 *Taking corrective action in due time*

The second obstacle to overcome when setting up an effective curative obsolescence treatment process is knowing how to take corrective action in due time.

Unlike the previous obstacle (gathering information), for which a central service alone can give 100% of the solution, decision making is a process that requires a great deal of internal organisation within each unit (we will deal with this subject in §4.3) and which can be made much easier by anticipation (we will deal with this subject in §3.2, 3.3 and 3.4).

However, a central service can still help significantly in finding solutions.

The Thomson-CSF group therefore decided to create an "Obsolescence Task Force" (TFO) with the task of helping the units find solutions.

In practice, the solutions can be very varied in nature:

1) searching for a strictly equivalent component,
2) searching for a more or less equivalent component,
3) creating a reserve stock,
4) buying stock available on the market,
5) sharing stocks between units,
6) negotiation with the supplier,
7) calling on after market companies,
8) producing a substitute component (ASIC or FPGA),
9) partial or total redesign of the card,
10) etc.

As we can see, some of these are purchasing solutions and others are technical solutions (or require technological expertise). They must all be decided on urgently. Finally, sharing between units is often an advantage, whether for finding solutions or implementing them, as knowledge is pooled, costs are shared, the units have greater weight in negotiations, etc.

The Obsolescence Task Force (TFO) is therefore made up of:

- a network of purchasing experts,
- a network of technical/technological experts,
- and a coordinator.

The coordinator is the single interface for all of the units whenever they need help regarding obsolescence. They can contact him at any time by email, fax or telephone. They can also visit his web site where they can find advice, warnings and in particular, the accumulation of answers to questions in an FAQ (Frequently Asked Questions) section. In many cases, due to his experience with such problems, the coordinator can answer the questions he is asked straight away. However, for new subjects he may consult one of the networks of experts. In addition, the coordinator, sometimes with the help of the networks, has the task of coordinating the research and implementation of solutions common to several units when it appears that a common solution is preferable to several separate solutions.

The purchasing network is made up of component buyers from the different units, who therefore have wide experience of concrete problems. They are both customers of the TFO when they are looking for a solution, and solution providers when another unit has asked a question via the TFO and they have the answer.

The technical network is made up of technological experts with in-depth knowledge of the components field. Most of these experts are in TTM, which has, amongst others, the task of evaluating the components and components processes for the whole of the Thomson-CSF group. These experts carry out systematic studies in the area of obsolescence on subjects such as:

- the interchangeability rules between technologies and the precautions to take,
- the extension of temperature ranges, upgrading, derating,
- the assessment through technical audits of the quality and reliability of the products offered by after market manufacturers,
- the methodological rules to follow to transfer an ASIC or FPGA design to a more recent generation,
- etc.

The units can consult the technical experts at any time on obsolescence problems, either directly or via the TFO coordinator. The results of their studies are made available to everyone on the TFO web site.

3.2 The tools and expertise to anticipate in the production or customer use phases

In §3.1.1 and 3.1.2, we mentioned what should be done every time an obsolescence warning arrived. Obviously, the problem of controlling the obsolescence risk cannot be resolved optimally using curative methods alone.

In addition to these methods, which remain vital, it is important to anticipate.

In §3.3 and 3.4 and later in chapter 4, we will discuss anticipation during the equipment design and development phases. In this paragraph, we will start by looking at what kind of anticipation can be done during the downstream production and customer use phases, that is, after the equipment is developed.

When obsolescence affects a piece of equipment, the very first reflex must be to ask whether further obsolescence is about to occur. Nothing proves that the solution (stock, upgrade, redesign, etc.) that seems best to handle obsolescence taken in isolation will remain the best solution if the fact that further obsolescence is about to occur is taken into

account in the economic analysis. For example, how much stock has been scrapped because soon afterwards, further obsolescence has meant that a module has to be completely reworked?

The difficulty is that if one waits for obsolescence to occur to carry out this analysis, it is often too late, as time is short and urgent action is required.

Again, the mature attitude is to anticipate. The part list for every piece of equipment must be reviewed regularly (every 12 months) and the following action taken:

- analyse the predicted end of life date of each component in the equipment,
- update the sales projections for the equipment,
- depending on these two analyses, update the projected redesign dates and the course of action to be taken until the next date.

To support the units in this procedure, the Thomson-CSF group decided to provide them with a tool and expertise; the tool, known as Technolife, is a database maintained and distributed by TTM that contains predicted end of life dates for a large number of components.

In addition, for components that are not in the database, the units have access to the component experts in TTM and other units (via the TFO). Furthermore, the answers given are amassed in the Technolife database and then updated every year, which allows Technolife to give excellent coverage of the components used by the Thomson-CSF units.

3.3 The tools and expertise to anticipate in the development phase

In §3.1 and 3.2 we mentioned what should be done to control the obsolescence risk during the production and use phases, that is, on equipment that has already been designed.

Taking the obsolescence problem into account on equipment in the upstream phases of the life cycle opens up many other levels of freedom.

During the development phase, and particularly when the list of components is selected, the level of freedom consists of choosing components with the best long-term availability prospects possible.

Unfortunately, although it is easy to set out this aim, it is costly to implement. Indeed, forming an opinion on the long-term availability prospects of a component requires market research, which has a cost. (It goes without saying that the manufacturer's sales pitch is generally not enough to gain an objective idea of the long-term availability prospects of the components in their catalogue!)

The route taken at Thomson-CSF to meet this aim at a reasonable cost was to try to cut the selection of components for all the units down to a very small number (see [4]). Initially (1994) when the decision was taken, the task seemed immense and almost insurmountable, as the areas in which the units worked seemed so diverse and their needs seemed so divergent. However, gradually, due to a highly reactive process in which each unit's needs, including for the most recent components, were systematically analysed and due to a better collective awareness of the risks involved in making inopportune choices, all of the units were able to agree on common choices for products being designed/developed.

Today, a very small set of components (2,500 parts, of which 500 are active) known as the Thomson-CSF components preferred parts list (PPL), allows most of the units in the group to cover approximately 80% of their needs.

From the point of view of obsolescence control, the use of the Thomson-CSF PPL is a very effective method, as it allows the following activities to be carried out for a cost shared between all of the units in the group:

1) market research so that the component with the best long-term availability prospects can be chosen, function by function.
2) regular updates of this market research in order to anticipate possible problems well before the official withdrawal announcements.

In reality, the benefits of the Thomson-CSF components PPL goes far beyond questions relating to obsolescence:

- regarding quality/resistance to environment, it allows for a similar procedure, i.e. in-depth analysis of the quality of the selected processes and monitoring changes to this quality over time. Remember that Thomson-CSF has implemented its own quality assurance policy to select the civil component processes (commercial or extended ranges) that offer sufficient guarantees to be used in extreme environments, with all the reliability necessary (see §2.2);
- regarding purchasing, it allows negotiations to be focused on a small number of components and suppliers, meaning that better conditions can be obtained (prices, deadlines, service);
- regarding the models necessary for CAD tools, the number of components to be modelled can be significantly reduced, thus reducing production costs;
- regarding exchanges of experience (technical, quality, purchasing), the fact that all of the units use the same components greatly encourages information exchanges.

In addition to the PPL tool, the units can also systematically turn to the TTM experts for part list reviews:

- for the unit, it is a way of understanding the various options possible and the associated risks,
- for TTM, it is an additional means of updating the PPL through analysing any inadequacies it may have on a specific project.

3.4 The tools and expertise to anticipate in the design phase

Approaching the obsolescence problem even further upstream, i.e. during the design phase of a piece of equipment, gives the advantage of a further level of freedom - designing an architecture that can better withstand component obsolescence.

We will not expand on this point, which is dealt with in §4.2.1. However, we will look ahead to the recommendation made in the conclusion to that paragraph: the evolution of the architecture over the whole life cycle must be analysed from the start of the project.

Unfortunately, technology evolves very rapidly (see the consequences of Moore's law in §4.2.1). It is therefore almost impossible to successfully analyse a life cycle if there is no tool that allows an overview of this technological evolution.

Such a tool has been set up within the Thomson-CSF group. This is a knowledge base known as Technoprice. Based on Moore's law and the expertise of the best components specialists in the group, it contains the forecasted evolution for the next ten years in the performance, price and functions of the components useful to the different units in the group. It is distributed to all of the units in the group.

Using the information it contains, it is possible to:

- gain a realistic idea of the performance upgrades and/or price decreases of a given architecture,
- gain a realistic idea of the performance and price of competing equipment in 5 or 10 years.

It is therefore a tool to optimise the choice of architecture in order to make the equipment competitive for as long as possible.

4. Methodological principles for obsolescence control in use in Thomson-CSF

In chapter 3, we listed the tools and expertise that the Thomson-CSF group provides all of the units for the most effective obsolescence control possible.

Of course, tools and expertise (that is, in both cases, information), are not sufficient to deal effectively with obsolescence. In addition, and above all, organisation and methods are required.

These must be put in place in each unit.

As we pointed out in §2.2, the organisation and methods can vary considerably from one unit to another, in that they must be suited both to the rest of the unit's organisation and in particular to the type of market and type of customer the unit targets.

However, this does not mean that there is nothing to pool within a group which, like Thomson-CSF, operates with a great variety of customers and markets. Hence, the working groups mentioned in §2.1 made the following analysis:

Firstly, simply sharing organisations and methods created by other units can be very useful as it is intellectually stimulating. The Obsolescence Task Force therefore created a "best practices" section on its web site. This offers a way for units to benchmark themselves against others. Moreover, the meetings of the obsolescence representatives organised by the TFO enable these best practice exchanges to be taken further through direct, informal contact.

However, it seemed possible to go further than simply exchanging best practices.

When the different best practices are analysed, it can be seen that the basic attitude behind them is to view obsolescence as a risk and look for remedies in a risk control type procedure.

This obsolescence risk control itself involves two rules of conduct:

1) upstream of the life cycle (design and development phases), knowing how to anticipate the risk in order to make the choices that will minimise the consequences when the risk becomes reality,
2) downstream of the life cycle (production and use phases), knowing how to be reactive, i.e. being able to take the decisions that enable the consequences to be minimised when the risk becomes reality.

The choices to be made upstream of the life cycle that have an impact on obsolescence control can be broken down into:

- management choices (with the customer playing a significant role),
- technical choices.

Downstream, reactivity is above all a matter of organisation.

We will therefore look at these three points in turn in the following three paragraphs.

4.1 Controlling the obsolescence risk upstream: the role of management and the customer

4.1.1 Thinking through the life cycle

As by its very essence, obsolescence has delaying effects (even though the acceleration of replacement of components makes these effects appear earlier and earlier in the programmes), the consequences and, most importantly, the cost of obsolescence can only be minimised if one thinks through the whole life cycle, right from the start of the programme, in an LCC (Life Cycle Cost) approach. It is clear (we will return to this point in the following paragraph) that choosing architecture that allows for a minimum cost for the first years of the life of a project does not necessarily mean that it will allow for a minimum cost over the whole life cycle. To go further, not only the acquisition cost of the equipment should be taken into account, but more generally the cost of ownership as seen by the customer and including the impact of the performance aspect. However, this does not alter the conclusion, which is that to minimise the LCC, the whole of the life cycle must be analysed right from the start of the programme.

4.1.2 *Clarify the rules with the customer*

It is clearly the responsibility of the programme manager and/or their customer to impose this type of life cycle reasoning we have just discussed. This might seem obvious, and so it is when the manufacturer is committed to supplying given quantities on given dates at a given price. It also is when the manufacturer is committed to keeping a product in its catalogue for a given period at a given price. In the second case, when the customer has not made a clear commitment on quantities, the manufacturer will make projections and base its strategy on these projections.

However, the rules are not always this explicit, particularly for contracts made with governments (and not only in the defence sector). For various reasons, the customer may have problems making a long-term commitment on order volumes and a specific schedule. When the customer is a government, the strong impact of politics can make volume and schedule projections very difficult for the manufacturer. Sometimes (and again, often for tactical or even political reasons), the customer might prefer an offer in which the initial acquisition cost is lower (as this will allow it to launch the programme) to an offer in which the overall cost of possession is optimised.

In all cases, and even if it is not pushed by its customer, the manufacturer's course of action must be to analyse the complete life cycle of the equipment, draw up a solution that minimises the LCC and offer it, even if only as an option, to the customer. The customer is then free to give another criterion for optimisation if this criterion meets its own constraints better. At least the ambiguity will be removed.

4.1.3 *Budgeting*

Once the principles of optimisation over the whole life cycle have been accepted by both the manufacturer and the customer, the manufacturer must evaluate the cost of obsolescence control and put in place the corresponding budgets (which, in certain situations, requires the customer's agreement again).

Again, this is obvious, but in 1995-1996, when the analysis was carried out, many contracts were faced with the obsolescence control problem without having budgeted for it. This often prevented the correct decisions being made in due time. The working group therefore felt that it was appropriate to set out this rule explicitly.

4.2 Controlling the obsolescence risk upstream: the importance of technical choices

4.2.1 *Incremental design*

When the decision is taken to optimise the LCC for a product, the immediate consequence is that the technical managers have to envisage the architecture of the product and its development over the whole life cycle in order to produce and optimise cost estimates. An analysis of Moore's law helps understanding the benefit of carrying out this exercise (and, incidentally, proves how difficult it is). This law states that on average the geometry of semiconductors decreases by 15% per year. This has proved true over the last 30 years and should continue to be so for at least the next ten. The consequence of this (see figure 3) is that chip performance doubles every 15 months, or increases tenfold every 4 years, or increases by a factor of 1,000 every 12 years. Unless it is prices that, for constant performance, drop by the same proportions, or any other intermediate solution.

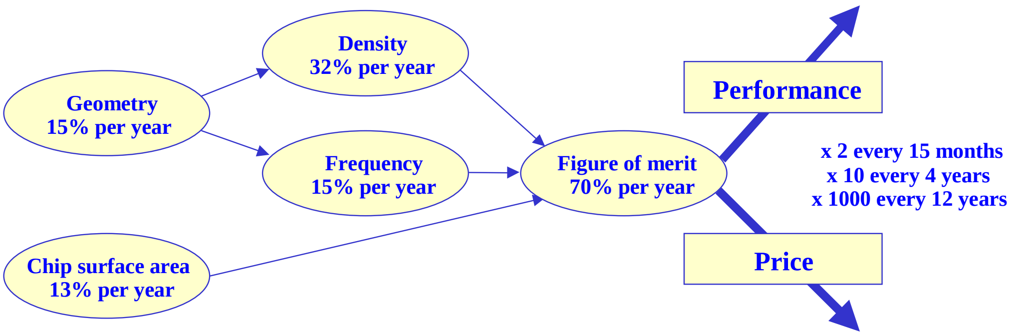


Figure 3: Moore's law and its consequences

This explains why the consumer industries are constantly bringing out new models: which child would buy a play station designed 15 months ago when a competitor has just brought out a new version that's twice as powerful? As a result, the components come onto the market and disappear one after the other at the same speed, fortunately with a lag on withdrawals due to production cycles.

The difficulty for the professional electronics industries is that the quantities sold are much lower and therefore the design and industrial development costs are proportionately a much greater factor in the production cost. Moreover, and for reasons of equipment homogeneity, the customer will want to be able to buy the same product for several years, or at least a product with an identical external interface – and yet still benefit from the price reductions due to technological developments.

In professional electronics, the manufacturer must therefore do the following simultaneously:

1) somehow resolve obsolescence problems so that it can continue production;
2) constantly improve the competitiveness of its products (price and performance) so that it can continue to sell;
3) minimise redesign/re-industrial development costs, which are very high overall.

The solution proposed within the Thomson-CSF group to reconcile these three aims is to use an incremental design procedure.

This procedure can broadly be compared with the well-known procedure in the US known as RASSP (see [6]). We will therefore limit ourselves to a general description of it.

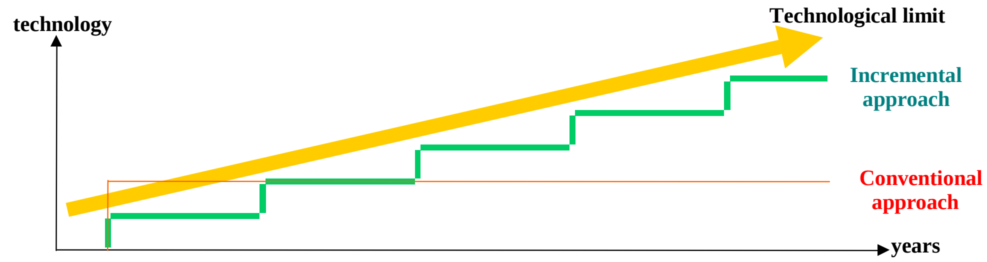
The aim of incremental design is to define a procedure to optimise the LCC. This procedure applies to the whole life cycle. The first stage (and probably the most important and most difficult stage) consists of analysing the LCC from the start of the project in order to optimise it. This involves making projections far into the future in order to anticipate changes in architecture and draw up estimates of the cumulative recurrent and non-recurrent costs over the whole life cycle of the equipment. In most cases, this LCC optimisation process leads to breaking the equipment down into modules and a strategy of gradually improving the modules one by one over the years. It also leads to a clear definition (stabilisation) of the portability interfaces between modules, so that one module can be upgraded without affecting the operation of the other modules. (It must be noted that these can be hardware or software portability interfaces).

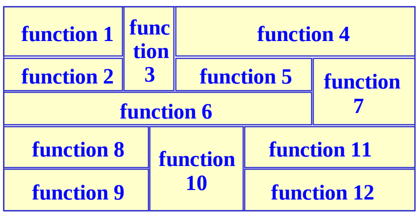
The idea is to take inspiration from the automotive industry. For years, manufacturers offer a product with the same name and more or less the same external interface. Every year, a new model comes out with an “extra feature” (increased performance, improved comfort, lower price, etc.) designed to make it more attractive to customers. However, the whole car has not been redesigned from scratch. Inside, everything is designed in modules, and every year one or two modules change and the rest remains identical.

This kind of process is the opposite of the process that used to be conventional in professional electronics, whereby a piece of equipment was designed to be reproduced identically for years. This often leads to specifying performance at the very limit of what was feasible at the time, and therefore to taking risks, increasing costs, causing delays, etc. This conventional approach is no longer conceivable today. After a few years, for one thing the original components have been withdrawn, there are no equivalents available and no-one knows how to produce the equipment any more. For another thing, competitors have placed a more recent and therefore higher performance, cheaper product on the market, and it is impossible to sell the old product. Moreover, the economic pressure on budgets means that the next generation cannot be redesigned from scratch.

The advantage of incremental design is that, due to anticipation and modular design, gradual upgrades to the equipment can be scheduled, which allows the manufacturer to avoid high and recurring redesign costs. From the customer’s point of view, this approach allows them to benefit from the advantages of technology progresses: enhanced performance and/or reduced costs.

Figure 4 summarises this approach and outlines the rules set out within Thomson-CSF for its implementation.





- LCC analysis and optimization from start of project
- Breaking down into functions
- Identification of lasting portability interfaces (HW or SW)
- Incremental development
  - Modeling
  - Simulation (virtual prototyping)
  - Fast implementation (fast prototyping)
  - Use of synthesisable components (ASIC, FPGA)
  - Specific effort on test environment
- Safety margins regarding technological limits

Figure 4: The incremental design approach

Of course, one can object that incremental design does not apply to all situations.

Firstly, it requires the customer’s cooperation. The customer has to accept that the equipment supplied throughout the whole life cycle will be compatible (it will have the same external interface), but not necessarily 100% identical inside. It must also agree to not demand extremely high levels of performance immediately, as this often makes it impossible to break the equipment down into modules. As a matter of fact, it is much better to build in safety margins regarding technological limits and break the equipment down into modules that will allow for the product to be improved over its whole life cycle: as performance is doubled every 15 months, it is better to implement a less than optimum solution very quickly rather than introduce delay just to gain 20%.

Secondly, the incremental design approach must be modulated/adapted for large production runs when recurrent costs are much greater than non-recurrent costs.

Thirdly, it may be hardly applicable when the product will have a very short life cycle.

However, even in this last case it (or more precisely, a variant of it) may be worthwhile if it can be applied simultaneously to several products; one interesting approach used by Thomson-CSF units with several products with similarities is to design common modules for the products and implement an incremental design policy for these modules, which often have a longer life cycle than the products.

In all cases, the rule is to analyse the evolution of the architecture over the whole life cycle from the start of the project. Whether it will be beneficial to use incremental design or a variant of it will become clear from the analysis. Technoprice (cf. §3.4) is the tool used at Thomson-CSF to provide the elements required for this analysis.

4.2.2 The COCISPER methodology

The almost complete withdrawal of MSI components today and the increasing scarcity of standard VLSIs in favour of components that provide increasingly specialised functions (ASSP or even ASIC) mean that the professional electronics industry has to turn increasingly to specialised components (ASIC or, if quantities do not allow for this, FPGA).

For the professional electronics industry, items such as FPGAs are an excellent response to obsolescence problems. As he possesses the VHDL description, the manufacturer has control on the function performed by the component and is in a better position to solve obsolescence problems. Furthermore, FPGAs also provide a solution to the problem of performance upgrades mentioned in the previous paragraph.

However, they are subject to obsolescence themselves.

In the event of obsolescence, it is important that the manufacturer knows how to “carry” the function performed by the obsolete component over to a more recent component at a low cost (often with the possibility of grouping functions together). To ensure this kind of control, French manufacturers have defined a methodology for mastering ASICs and FPGAs lifecycle with the help of the DGA. A description of this can be found in another paper at this conference (see [7]).

4.2.3 The use of a components preferred parts list

We will not go over this subject again, as it was amply covered in §3.3. However, it is obvious that using components carefully selected for their long-term availability prospects and then carefully monitored for obsolescence is a major factor in minimising the obsolescence risk.

4.3 Controlling the obsolescence risk downstream: the role of organisation

4.3.1 Organisational reactivity

In the downstream phases (production and use phases), that is, once the equipment has been designed and developed, the main skill a manufacturer needs to control obsolescence is reactivity, i.e. the ability to make the right decision in due time (often very quickly) when a problem arises. It must be noted that, in some serious situations when the manufacturer will not be able to manage the problem alone, it will have to inform the customer and decide with it what steps to take. This is also part of the “right decision”.

It is well known that in a company, the key to reactivity is organisation.

However, this is also where the main difficulty lies when it comes to obsolescence. Reactivity in the event of obsolescence requires the implementation of a fairly complex process within the company as:

- several activities are involved:
  - purchasing (which encounters the problem, and can also suggest solutions),
  - production (which has to be reorganised),
  - technical (which can also suggest solutions),
  - project management (which has to arbitrate),
  - sales (if there are sales consequences),
- very often several contracts, or even several products are affected, so that the optimum decision must be made by several people in the light of constraints (volumes, deadlines, customer wishes, etc.) that can vary significantly from one contract to another.

Faced with this problem, the Thomson-CSF units have implemented rather varied organisations.

For example, in a unit that had designed a strategy of modules that were reusable from one product to another, the organisation chosen was to set up a body with the task of guaranteeing the supply of modules to the products in spite of obsolescence problems. This body finances the action necessary for effective obsolescence management with a percentage of the price of the modules delivered.

In another unit with ASIC based products, the organisation chosen was to systematically analyse all current and foreseeable needs (raised by either obsolescences or upgrading policy) for every product so that every ASIC designed covers as many of these as possible.

It is nevertheless rather difficult to transpose such best practices from one unit to another, as they are very much linked to a local situation (organisation, type of product, customer, etc.).

The decision within the Thomson-CSF group was therefore to simply collect these best practices together and make them accessible to everyone, but purely for guidance.

However, it did seem useful to highlight a certain number of rules of conduct. These rules in no way impose a type of organisation. They form a list of questions to ask in order to judge whether or not a type of organisation is appropriate. They appear in a document, the “Thomson-CSF Baseline”, which groups together the rules that all units should follow, activity by activity.

These are just a few of them:

- systematically analyse all of the obsolescence warnings,
- identify their impact on all of the equipment,
- immediately analyse the consequences of this,
- take into account all of the contracts and products affected,
- take advantage of the synergies between products to combine equipment upgrades and obsolescence management,
- make sure that the decisions taken are followed up in the deadlines,
- in particular, comply with the LBO dates,
- inform sales of the consequences of obsolescence on costs and deadlines.

As will be seen, these are all very obvious, if not banal, points. However, when these rules were drawn up in 1994-1995, they had their uses. Although they are easy to say, they are much more difficult to implement in a complex organisation. Readers with experience in industry will doubtless agree.

4.3.2 Ability to anticipate problems

Given the complexity of the process mentioned earlier (gathering of information + decision making), obsolescence warning times that might seem quite comfortable (typically 3 to 6 months) are in fact very short, so the final decision is often taken urgently.

A good way to increase reactivity is to know how to anticipate the problem.

This is why it is beneficial, as mentioned in §3.2, to review the part list for every piece of equipment regularly (every 12 months) in order to:

- analyse the predicted end of life date of each component in the equipment,
- update the sales projections for the equipment,
- depending on these two analyses, update the projected redesign dates and the course of action to be taken until the next date.

Moreover, anticipating problems through systematic part list reviews is not just a way of increasing reactivity. As pointed out in §3.2, it is also a way of finding the optimized solution, i.e. a solution that, instead of solving problems individually as they arise, incorporates them into a more general and probably more cost-effective procedure.

5. Conclusion

Controlling obsolescence problems, i.e. the ability to offer long-term availability and/or upgradeability (depending on the customer’s requirements) is therefore increasingly seen as a fundamental component of professional electronics manufacturers’ know-how.

It responds to increasingly high expectations from all types of customer, whether domestic or export, in aerospace, defence, telecommunications or industry.

This control means that the manufacturer must implement an organisation, principles, methods and tools that guarantee its customers:

- a systematic attitude of risk anticipation and limitation, from the most upstream phases to the most downstream phases of a programme, in order to set out the most pertinent strategy at all times,
- excellent reactivity to deal with problems quickly and effectively when they arise,
- a relationship of trust between the manufacturer and its customer, in which the manufacturer keeps the customer informed of the main actual or potential problems and advises it on its requirements, so that these requirements encourage the implementation of an effective obsolescence control strategy.

The system described in this paper, implemented by TTM and currently fully operational within Thomson-CSF, shows how common tools and methods can greatly help each of the units in the group offer every customer the most professional and cost effective process to guarantee this level of obsolescence control.

This system must itself come within the framework of organisation and processes specific to each unit, as they depend to a large extent on the specific context of each field, market and customer.

The Thomson-CSF group is willing to allow other manufacturers to use all or part of this system within the framework of a partnership agreement, and to reap its benefits.

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About the author

Gérard Gaillat is the Technical Director of Thomson-CSF Technologies and Methods (TTM).

TTM is a corporate entity with the task of setting out and implementing the methods, tools and technological choices common to all of the Business Units in the Thomson-CSF group.

In this framework, TTM is responsible for co-ordinating the Thomson-CSF group's anti-obsolescence strategy, defining the methods for this and distributing common tools.

Gérard Gaillat is also a member of the EDIG (European Defence Industry Group) Technical Committee, on which he represents the French defence electronics industry.

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Transitioning to Integrated Modular Avionics with a Mission Management System

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1 SUMMARY

This paper presents an incremental approach towards the adoption of an Integrated Modular Avionics (IMA) architecture, via the implementation of a Mission Management System using present-day Commercial Off-The Shelf (COTS) technology.

While standardised IMA modules are planned to be developed in the medium term, the approach presented enables the maximum benefits to be obtained from those aspects of the IMA concepts which are the most advanced, while exploiting the availability of today's COTS hardware. This approach is embodied in the Mission Management System, which is under development at ESG.

The Mission Management System is a computer-based system which is intended to host advanced mission management applications focussed on crew assistance functions, including mission planning and terrain-based display. The hardware of the Mission Management System comprises a single unit, the Mission Management Computer. The system, and in particular its software structure and system management functions, are based on the IMA concepts developed in the ASAAC (Allied Standardised Avionics Architecture Council) programme, which are applied here to the extent that they are compatible with the available COTS components. The Mission Management System implements those elements of the ASAAC IMA concepts that are most suitable for near-term adoption, and in particular those related to the software structure, which is based on the use of a COTS Real-Time Operating System.

In implementing the IMA concepts from ASAAC, the Mission Management System is designed around an open system architecture, using COTS hardware and software components. This approach provides technology transparency, and supports the substitution of system components, such as the replacement of system hardware or the Real-Time Operating System implementation, to mitigate the effects of hardware and software component obsolescence.

The paper first presents the approach adopted in transitioning towards the IMA architecture via the use of current-day COTS components. The Mission Management System is then described from the system architecture, software architecture and hardware architecture points of view, noting the implementation constraints of current COTS components. The system characteristics which are achieved through the adoption of the relevant IMA principles together with open systems and COTS practices are presented.

The mission management functions to be implemented on the system are defined, and an example is then presented of a complete avionics system built using the transitional technology of the Mission Management System in a number of Integrated Computers to provide a complete computing core.

Some certification issues are discussed, and the adoption of an incremental certification approach is recommended. A path forward towards the development of a true IMA system implementation is proposed, including further development of the Mission Management System, and the migration to a modular implementation.

2 INTRODUCTION

Integrated Modular Avionic concepts for military aircraft have been developed under a number of national [Ref. 1] and international projects, the latter including in particular the completed European EUCLID RTP 4.1 programme [Ref. 2], and the key ASAAC programme [Ref. 3, Ref. 4, Ref. 5].

The IMA concepts developed, and particularly those of the ASAAC programme, are based on the principles of modular systems, open systems and COTS. In an IMA architecture, the computing capacity is concentrated into a 'Core', which consists of interchangeable processing modules of a limited number of standardised types, particularly for data, signal and graphics processing. IMA systems provide a high level of technology transparency by being based on a set of open standardised interfaces, so facilitating the replacement of hardware components without affecting the application software. In addition, the use of open standardised interfaces directly supports the use of COTS components, which is of great benefit in combating the effects of component obsolescence. IMA systems also implement fault tolerance, so that when a module becomes defective, the system reconfigures and a spare module takes over the functionality of the failed module. The IMA concepts developed in the ASAAC programme have been adopted as the basis for the Mission Management System reported on in this paper.

Paper presented at the RTO SCI Symposium on “Strategies to Mitigate Obsolescence in Defense Systems Using Commercial Components”, held in Budapest, Hungary, 23-25 October 2000, and published in RTO MP-072.

The development of the required set of ASAAC IMA hardware modules will be a substantial task, and its completion lies some way off in the future. Even given the availability of hardware modules, a very considerable certification effort will be required to qualify an ASAAC IMA-based system, particularly due to the system-wide configurability under software control it exhibits.

It is, however, possible to exploit the elements of the ASAAC IMA system, software and hardware concepts which will have been developed before such a stage is reached, while using the COTS-based board-level hardware components available today. Such advanced IMA concepts may be implemented in systems without expending significant additional effort in comparison with a more conventionally based solution. In this way a significant number of the benefits promised by the IMA architecture may be achieved today: a key example is the use of technology transparency to combat obsolescence.

A transitional step towards the implementation of the true IMA architecture is therefore now being taken with the development of a Mission Management System. In defining the Mission Management System, the aim has been to define a demonstrator which will allow the implementation of a representative set of application functions, using an architecture based on the IMA architecture of ASAAC. This will permit progress to be made towards the implementation and certification of an IMA-based avionics system, by gaining experience in the implementation of an ASAAC IMA-based software structure, and evaluating the consequences of hosting applications on such a structure.

The Mission Management System is designed to exploit:

- *The ASAAC IMA concepts:*
  Currently available elements of the ASAAC IMA concepts have been realised.
- *Open system architectures:*
  In accordance with the principle of offering an open architecture, open standards have been adopted. The use of an open architecture supports especially technology transparency, application portability and system scalability.
- *Available COTS hardware and software technology:*
  Extensive use is made in the Mission Management System of COTS components, both hardware and software. The use of COTS supports particularly the lowering of system costs and reduction of development time.

By the adoption of these concepts in the Mission Management System, it is aimed to achieve the following characteristics typical of IMA systems:

- *Application Portability:*
  The portability of application functions between hardware platforms is supported in turn by technology transparency.
- *Technology Transparency:*
  Technology transparency embraces hardware independence, which supports hardware replacement for future system upgrading and to counter component obsolescence, network independence, which enables the network technology to be upgraded, and also extends to the software technology.
- *Scalability:*
  Scalability supports the application to avionic systems of different sizes and roles, as well as future avionic system growth. The scalability characteristic is in turn supported by technology transparency, in particular by hardware and network independence.
- *System Reconfigurability:*
  By reconfiguring the system depending on the system mode, the total resource requirements of the system may be reduced. Reconfigurability may be used on the occurrence of faults to support fault tolerance.
- *Fault Tolerance:*
  Fault tolerance may be used to improve system reliability, and is supported in turn by system reconfigurability.

3 SYSTEM ARCHITECTURAL CONCEPT

3.1 Key Concepts

The architecture of the Mission Management System (MMS) is a transitional architecture between that of the current generation of federated architectures, and future IMA architectures. It is designed to be compatible with the avionics system architectures of both new-build aircraft designs and retrofit applications.

The architecture defined for the MMS utilises the elements of the ASAAC concepts which are the most advanced, but which are also compatible with conventional federated avionics systems. The aspects of the ASAAC concepts which have been adopted lie mainly in the Software Architecture and System Management areas, although some aspects of the hardware concepts have also been employed. The following key concepts have been applied:

- Use of a standardised interface between Application Software and the Operating System Layer.
- Hardware abstraction by software.
- Use of a system management structure and 'Blueprints' which together support system configuration and reconfiguration.

- Use of a standardised software interface for all data communication.

Due to the requirement to be able to integrate the MMS within a conventional federated avionics system, the aspects of the ASAAC IMA concepts which extend throughout the entire avionics system have necessarily found only partial application. These include for instance the system health and configuration management concepts.

3.2 Open Architecture

Open architectures are characterised by the use of widely accepted and supported standards set by recognised standards organisation or the commercial market place. As the standards are available to all, a system based on an open architecture is open to the incorporation of components from potentially any source. The IMA architecture defined in ASAAC is such an open architecture, as it both defines its own open standards, and supports the use of available open standards in its implementation.

An ASAAC IMA system may be regarded as comprising a set of application functions hosted on an open architecture platform. The applications are not dependent on the underlying technology and hardware, as the interface between the applications and the system functions is established as an open standard, so allowing different manufacturers of software and hardware components to contribute to the system.

A common example of an open architecture in the commercial world is the POSIX system [Ref. 6], which allows Unix systems and applications to be developed independently of the underlying hardware, regardless of the hardware manufacturer. While POSIX is unsuitable for an IMA System, which requires fully predictable real-time behaviour of its components, applications in ASAAC IMA systems are hosted on an open platform with an open interface, the Application to Operating System layer (APOS) interface (see Sec. 4.3).

3.3 Modes and Configurations

In the MMS, the various mission management functions are each only required to operate during the relevant phases of the aircraft's mission. For example, different mission planning functions are likely to be applicable to different mission phases, and display functions for high-altitude combat air patrol would differ from those for low-level target ingress.

In order to optimise the utilisation of the hardware resources in the MMS, and so reduce the total system resource requirements, the same hardware in the MMS will be used to host different application functions at different times, according to the requirements of the mission phase.

Because of the strict separation of application function design from the system hardware design, it is possible for the MMS application functions to be distributed over the hardware in a number of different ways, and hence for an application to be easily transferred from one processor to another.

At the transition from one mission phase to another the MMS will be reconfigured by halting and removing the relevant software components from the processors, and loading and starting new components from the Mass Memory Unit.

A set of MMS modes is defined to cover the various phases of the mission, where a specific set of functions runs in each mode. Within each mode, a number of different configurations of the functions on the various hardware resources may also be possible.

3.4 Fault Tolerance

ASAAC IMA systems offer fault tolerance by reconfiguring on the occurrence of faults. A new module may be substituted for a faulty module, and the application functions reconfigured accordingly. The fault tolerance concept of the MMS is derived from that of ASAAC IMA systems.

It is not possible to implement the same degree of redundancy in the MMS as in the ASAAC IMA concept, as the latter relies on full hardware redundancy between modules. The components of the MMS, on the other hand, are integrated with one another at a lower level: powering on and off individual hardware components is not supported within the MMS, for instance.

The MMS implements a limited degree of fault tolerance. Some redundancy is likely to be available between the multiple instances of the various hardware components, such as the Single Board Computers (SBCs) which are used within the MMS. Where such redundant capacity is available, when a component becomes defective, the system is reconfigured so that a spare component takes over the functionality of the failed one. Alternatively, where no extra resources are available, non-critical functions may be dropped, to free resources for higher priority functions, or reversionary implementations of functions, with lower resource requirements, may be used. In this way, a significantly greater fault tolerance capability is achieved than with conventional systems.

3.5 System Management

ASAAC IMA systems implement a standardised system management structure that is responsible for performing the following major functions:

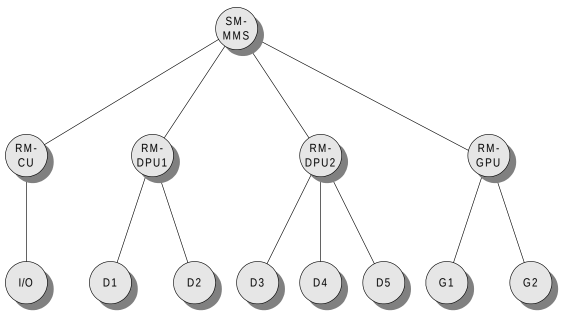
- Initialisation and shutdown management.
- Configuration management, including reconfiguration on mission mode transitions and on faults.
- Fault management, including health management such as the processing of Built-In Test (BIT) data.

For the Mission Management System, elements of the ASAAC IMA system management have been adopted as appropriate. Whereas the ASAAC system management concepts, such as for instance health management and configuration management, generally encompass the entire avionics system, it has only been possible to implement these within the scope of the MMS.

One of the prime responsibilities of system management is managing the control of the application functions, which includes their instantiation, start, suspension and removal from the system. System management is also responsible for configuring communications between applications, which is performed in a similar manner to the process scheduling, in order to guarantee predictable communications.

The system management functions manage the system in accordance with the blueprints. The blueprints provide the definition of the system resources, and define the possible configurations of the system. The configurations are deterministic, and are defined at design time: such strict system control will be necessary in order to certify the system. As well as the configurations themselves, the blueprints also define the reconfiguration processes which are carried out on the occurrence of faults.

System management in the ASAAC IMA concept is performed throughout the avionics system on a hierarchical basis. In the MMS, system management is performed at two levels. The top-level manager is the System Manager, and this controls the Resource Manager, which manages a particular single board computer hosting a number of application functions. Figure 1 shows the MMS system management hierarchy.



SM	System Manager	RM	Resource Manager
CU	Communications Unit	DPU	Data Processing Unit
GPU	Graphics Processing Unit	I/O	Input / Output
D1-Dn	Data Processing Processes	G1-Gn	Graphics Processing Processes

Figure 1: System Management Hierarchy

The MMS system management differs from that of the ASAAC concepts primarily as follows:

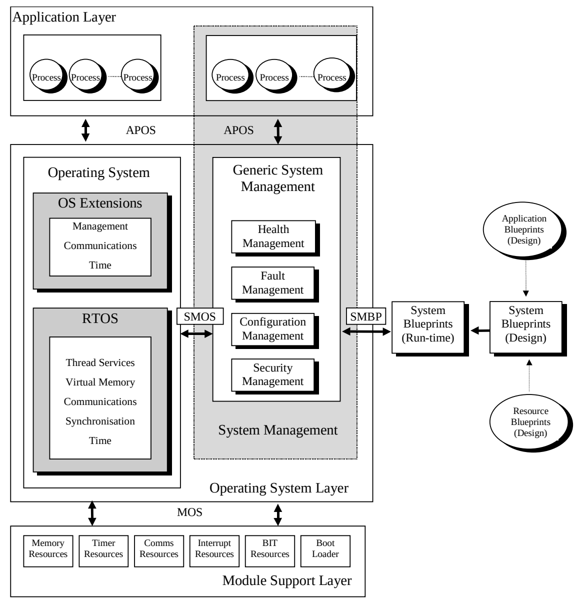
- The system manager hierarchy is limited to two levels.
- Fault detection is dependent on the capabilities of the COTS components.
- Only limited reconfiguration is supported, particularly for fault tolerance.
- The ASAAC System Management Blueprint (SMBP) interface between the GSM and the blueprint data is not implemented.

The system management functions are implemented by the software of the Generic System Management (GSM: see Sec. 4) together with the blueprint data, which are provided as part of the software load.

4 SOFTWARE ARCHITECTURE

4.1 The ASAAC Software Architecture

The software architecture of the Mission Management System is based on the ASAAC software architecture, modified to suit the COTS-based hardware architecture of the MMS.



APOS	Application to Operating System Layer Interface
BIT	Built-In Test
MOS	Module Support Layer to Operating System Interface
OS	Operating System
RTOS	Real-Time Operating System
SMBP	System Management Blueprint Interface
SMOS	System Management to Operating System Interface

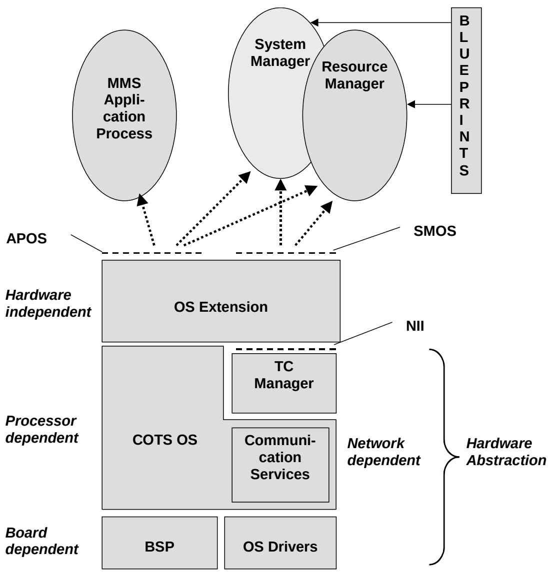
Figure 2: The ASAAC Software Architecture

The main components of the ASAAC software architecture are the Application Functions, the Operating System (OS), the Generic System Management (GSM) and the Runtime Blueprint representation (RTBP), as depicted in Figure 2. The GSM defines and manages the processing and communication resources required by the application, and the operating system provides the application with access to these resources. The blueprints provide the definition of the resources and of the possible system configurations. The GSM and the runtime blueprints are associated with both the system hardware and the application-independent operating system layer.

This architecture is based on the principle of a three-layer software stack, where the layers have the following properties:

- *Application Layer*
  Application Dependent, Hardware Independent
- *Operating System Layer*
  Application Independent, Hardware Independent
- *Module Support Layer*
  Application Independent, Hardware Dependent.

This architecture as implemented in the MMS is illustrated by Figure 3.



APOS Application to Operating System Interface
BSP Board Support Package
NII Network Independent Interface
OS Operating System
SMOS System Management to Operating System Interface
TC Transfer Connection

Figure 3: Design of the MMS Software Stack

In this design, the ASAAC software architecture has been adapted to the requirements and constraints of a computer architecture based on COTS VME hardware and a COTS real-time operating system:

- There is no Module Support Layer: hardware abstraction is achieved by the architecture of the real-time operating system.
- The GSM function is simplified into two kinds of management functions, a top level System Manager, which controls the overall computer, and a Resource Manager for every single board computer, which controls the board local resources.

4.2 Hardware Abstraction

A prime property of the ASAAC software architecture is the independence of the application software from the hardware, as the highest costs that arise in the replacement of obsolete hardware are incurred in the consequential adaptation of the application software.

In the ASAAC software architecture, a hardware abstraction layer is provided in the form of the Module Support Layer (MSL). This hardware abstraction provides the system with hardware independence: the higher software layers are independent from the hardware details, so that hardware changes do not affect either the operating system layer or the application layer software, so countering the effects of component obsolescence. In the Mission Management Computer, this architecture has been adapted to the architecture of a COTS real-time operating system. This adaptation provides the same hardware abstraction characteristics as specified for the Module Support Layer.

This hardware independence is provided at the level of source code compatibility, as binary compatibility would require a much higher degree of standardisation. Standardisation down to the level of binary compatibility has to be very detailed, and is therefore very restrictive, so limiting the openness of the architecture. Source code compatibility appears for this reason to be the appropriate choice.

In addition to the issue of source code compatibility, hardware modifications are likely to result in changes in the resource characteristics of the hardware, such as enhancements to the processing power or communication capacity, which would affect the system operation. This issue is addressed by separating the configuration data from the system management functions, and encapsulating it in the form of blueprints. A change of hardware or the porting of an application to another system would therefore only require the adaptation of the blueprints and the recompilation of the relevant software, including the operating system layer and application code.

4.3 The Operating System Layer

The Operating System Layer includes the Operating System itself, together with the system management components, ie. the system managers and the run-time representation of the system's blueprints.

One of the chief benefits from the use of the ASAAC software architecture for the Mission Management System is application portability, which supports the reuse of the application software. Application portability is provided primarily by the use of a standardised Application to Operating System (APOS) layer interface. As it is the only interface of the ASAAC software architecture visible to the application, the application is dependent only on this interface for the satisfaction of its processing and communication resource requirements. As the Mission Management System offers the same APOS as any ASAAC system, the mission management applications are therefore portable to other systems built using the ASAAC standards.

A COTS real-time operating system is used as the core of the operating system layer. In comparison

with the alternative approach, which is the development of a bespoke operating system, the COTS approach exhibits greater flexibility and cost efficiency due to the commercial support provided for the adaptation to new hardware components. The use of a COTS operating system supports the efficient implementation of the operating system layer on the underlying COTS hardware, both for the MMS hardware, and for ASAAC IMA systems. A COTS Real-Time Operating System is therefore well suited to support the transition from the federated system architecture of the MMS to an IMA system, providing a stable Application Programming Interface together with off-the-shelf compatibility with COTS hardware.

The COTS operating system is complemented in the operating system layer by additional software which provides the adaptation to the ASAAC operating system interfaces, and in particular to the APOS.

4.4 Application Function Software Structure

The application process is the basic software element of an application function, and represents the configuration unit of a system. Each application process depends on processing and communication resources, namely on threads and virtual channels, and can only be executed when the system management function provides its required processing and communication resources.

In the Mission Management System, three different kinds of application processes have to be accommodated: data processing processes, graphics processes and mass memory -related processes. The last of these includes such processes as database applications, and is implemented in the form of file access functions. While data processing and mass memory applications may be freely located on any processor, graphics processing is restricted to the specific hardware capable of providing the OpenGL interface and functionality.

The mission management application is built from a number of small but simple processes, most of which contain only a single thread, and which are configured in accordance with the currently active mission mode. Each of these processes depends on both transient data and persistent information: the transient data is provided via the MMS interface, and the persistent information from a central database, which is represented by an application process that provides information on request.

4.5 Properties of the Software Architecture

The software architecture of the MMS offers a number of beneficial properties in comparison with conventional systems.

Application portability and technology transparency are both provided by the use of the APOS as a standardised interface between the application software and the operating system layer. This permits the reuse of the application software on other systems offering the ASAAC APOS interface, and also the replacement of the MMS hardware without modification of the application software source code. Performing the application design independently of the underlying hardware is also supported.

In addition, hardware abstraction below the level of the APOS provides protection against component obsolescence, by supporting hardware independence.

Technology transparency in the MMS also extends to software technologies: as the APOS is independent of the underlying COTS OS used, the COTS OS may also be replaced without affecting the application functions.

The GSM and blueprints support the ability to reconfigure the system in accordance with the mission requirements, so providing for efficient hardware use, and also supporting fault tolerance, which contributes to improved system reliability.

The open standards used include the open commercial standard OpenGL, and the ASAAC standards. COTS components used include the COTS operating system, together with its board support packages and drivers.

Due to the intention to maximise the use of COTS components in the development of ASAAC modules, the approach adopted for the Mission Management Computer of employing the ASAAC software stack with a COTS operating system is likely to remain effective throughout the continuing transition from today’s federated system architecture to tomorrow’s IMA architectures.

5 HARDWARE ARCHITECTURE

5.1 The Mission Management Computer

While current work is focussed on the software structure, using laboratory development hardware, the Mission Management Computer (MMC), which would form the hardware of the Mission Management System in a real aircraft application, and on which the application functions would run, has also been defined.

In an avionics system application, the Mission Management System would be integrated with and exchange data with other avionics system computers and peripheral devices, including sensors, effectors and displays and controls: a possible system implementation is shown in Sec. 7.

In order for the MMS to be able to perform the required application functions, the MMC must support the relevant low-level functions, which include data processing, graphic display processing, provision of mass memory, and communication. The MMC has been defined for hosting the MMS functions discussed in Sec. 6.

5.2 Structure and Packaging

The packaging concept of the MMC differs considerably from that of IMA systems. Whereas in

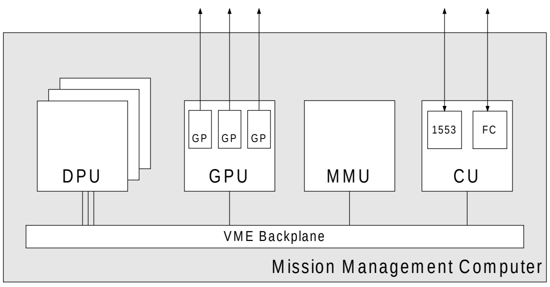
an IMA system, the line-replaceable items are the individual modules, the MMC is, in line with contemporary avionic systems, itself the line-replaceable item.

The basic principle behind the construction of the MMC is the exploitation of available COTS components, and in particular the use of VME boards. This enables the demonstrator to be built using standard commercial grade racks and boards, and a ruggedised version suitable for service use to be produced using components qualified to the appropriate environmental standards. In an aircraft application, the MMC would take the form of a standard ATR format unit, which would be mounted on an ATR rack in the avionics bay.

While the application of the IMA hardware concepts to the MMS is limited by the use of pure COTS hardware for the MMC, the hardware structure of the MMC has been influenced by the ASAAC concepts where possible, in order to support the ASAAC software and system architecture concepts employed, and to support the future development path towards an IMA system.

The structure of the MMC therefore conforms with the ASAAC concepts in the segregation of the data processing, graphics processing and mass-memory capabilities. Areas in which the structure of the MMC diverges from the ASAAC structure include the separation of the external communications interface from the processing capacity, and the lack of a Module Support Unit local to each of the processors. Power-Up and Continual Built-In Test are implemented to the degree that these are supported by the COTS hardware.

The structure of the MMC is shown in Figure 4 below, and discussed in the following text. The MMC is constructed using 64-bit VME boards: where required, for instance for communications, PMC modules are mounted on the VME cards.



DPU	Data Processing Units 1-3	GPU	Graphics Processing Unit
GP	Graphics Processor	MMU	Mass Memory Unit
CU	Communications Unit	1553	Mil Std 1553B
FC	Fibre Channel		

Figure 4: The Mission Management Computer

5.3 Hardware Components

The MMC consists of four main types of VME-bus component:

- Data Processing Unit
- Graphics Processing Unit
- Mass Memory Unit
- Communications Unit.

The data processing hardware comprises three Data Processing Units, each taking the form of a PowerPC Single Board Computer (SBC).

The graphic display processing implements three graphics processing channels, and so provides the capability of driving three displays with separate formats. The graphics processing hardware comprises a Graphics Processing Unit, consisting of three 3D graphics PMCs supporting OpenGL, mounted on a PowerPC SBC. Each graphics processor PMC provides the following key features:

- OpenGL implementation
- 1024 x 1024 resolution
- 1 M three-dimensional-polygons / sec.

The Mass Memory Unit is implemented as a solid state memory or hard disk interfaced with a PowerPC SBC.

The Communications Unit consists of the relevant network interfaces implemented as PMC modules mounted on a PowerPC SBC: in addition, analogue and discrete input / output is provided for as required.

5.4 Data Communications

All data communication within the MMS between processor boards and between the MMS and external equipment takes place via a standardised software network interface, termed the Network Independent Interface (NII), which has been derived as part of the ASAAC concepts. Data transfer takes place through the NII via a Transfer Connection (TC), which acts as a virtual channel, and which is established explicitly prior to the data transfer.

The use of the Network Independent Interface provides the ability to change the network technology used, for instance when reconfiguring the system and re-routing a particular transfer from an MMS-internal transfer to an external transfer. The network technology used for external transfers might also be upgraded as part of a future system improvement.

Communications within the MMC takes place using the buses available with the COTS boards, such as the VME and PCI buses.

The network technology used for external communication depends on the particular avionics system implementation into which the MMS is integrated: options range from the conventional Mil-Std 1553 command / response bus or ARINC 429 data distribution bus, to a high-capacity optical serial COTS Fibre Channel network.

5.5 Properties of the Hardware Architecture

The hardware architecture of the MMS offers a number of beneficial properties in comparison with conventional systems.

Technology transparency is supported by the Network Independent Interface, which provides for the replacement of the network technologies used while maintaining the software interface to the network, so allowing for data transfer growth.

Support is provided for scalability and system growth, particularly by the use of an open COTS-based architecture. The MMC is capable of being extended to cater for the addition of further MMS functionality, should this be required for a particular system application. Further data processing SBCs may be added to provide the required capacity, and the number of graphics processing PMCs may be chosen to feed the number of displays required. Hardware components of the computer may be replaced, providing that the availability of the relevant COTS operating system, board support package and drivers is assured.

Within the MMC, a limited degree of interchangeability between components could be offered by the use of a number of identical VME SBCs and PMC modules.

Open standards used in the MMC include open commercial standards as ATR, VME64, PCI, PMC and Fibre Channel, open military standards such as Mil-Std-1553B, and the ASAAC standards.

Use is made of Commercial (COTS) and Military Off-The-Shelf (MOTS) components as follows:

- SBCs, PMCs: COTS boards, using commercial chip-level components.
- Network: COTS, MOTS.

6 MMS FUNCTIONALITY

6.1 Generic Mission Management Functions

The possible system applications of a Mission Management System extend across a range of aircraft roles, from combat aircraft, including rotary wing types, to heavier patrol and transport aircraft. The specific functions implemented on the Mission Management System in a particular avionics system implementation would depend on the role of the aircraft and the allocation of functionality within the complete avionics system.

Typical mission management functions include the following:

- Situation Assessment
- Conflict Management
- Mission Planning
- Man-Machine Interface
- Navigation
- Flight Guidance.

The functional structure of a Mission Management System is shown in Figure 5 below.

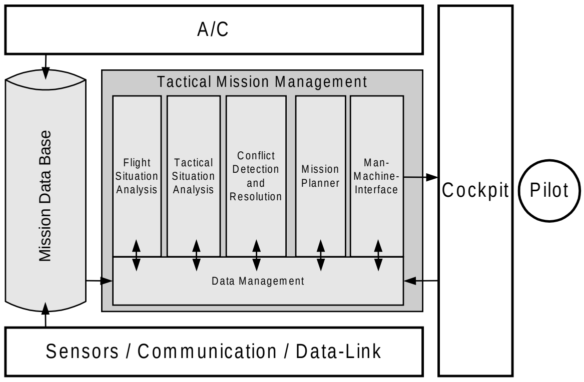


Figure 5: Functional Components of a Mission Management System

6.2 Functions Selected

For the Mission Management System under development, a representative set of functions which is broadly aimed at a multi-role fighter application has been chosen.

The primary functions selected are mission planning, representing a high-performance data processing application, and the production and presentation of perspective flight guidance information, a three-dimensional graphic application.

These functions are based on those under development in parallel activities being performed at ESG, as previously reported [Ref. 7], and are now to be ported to the Mission Management Computer from their original implementations on a laboratory workstation-based environment.

To provide the required functionality, the Mission Management System will comprise the following functional components:

- *Databases:*
  - Terrain Database
  - Navigation Database
- *Functional components:*
  - Threat Analysis
  - Mission Planner, including:
    - Transit Planner
    - Low-Level Flight Planner
    - Attack Planner
- *Graphics processing:*
  - Head-Up Display with Terrain Graphics
  - Head-Down Display with Synthetic Vision
  - Tactical Navigation Display.

External inputs received by the MMS from other avionics system components include:

- Aircraft Data (eg. Position, Velocity, etc.)
- Sensor Data (eg. Threat warnings, Datalink).

Details of the functions have been given previously in [Ref. 7].

The functional structure of the system has been designed to accommodate the addition of further functional components as and when required, depending on the requirements of the anticipated application avionics system.

7 AVIONICS SYSTEM ARCHITECTURE

7.1 Architectural Concepts

This section addresses the system architecture of an avionics system into which the Mission Management System might be integrated. The system example described here is a near-term new system design, again based on a multi-role fighter application.

The proposed system architecture is based on the use of Integrated Computers, of which the Mission Management Computer is an example, each based on the same system, software and hardware architectures as described for the MMS above.

The avionics system structure remains essentially a federated architecture. As in conventional federated systems, the overall avionics system is divided into a number of dedicated systems / sub-systems, eg. Mission Management System, Stores Management System. The overall system consists of a number of Integrated Computers, together with essentially the same dedicated equipment found in conventional federated systems, eg. Radar, Radio, Displays and Controls.

The computing capacity of the avionics system is distributed between the Integrated Computers, which are interconnected via the communication network. In comparison with other federated architectures, the Integrated Computer-based architecture is characterised by the centralisation of the processing capacity in a smaller number of higher-capacity processors.

Most of the processing of the sensor data, including the signal processing, takes place in the sensor equipment itself, whereas the subsequent system-level data processing of the sensor data is performed in the Integrated Computers. The degree to which the sensor data processing is implemented in the Integrated Computers depends on the capability provided by the particular sensors themselves.

System management, embracing moding, configuration management and fault tolerance, would initially remain implemented largely at the level of the Integrated Computers, rather than being integrated at an aircraft level, as with an ASAAC IMA system. However, for critical functions additional reversionary implementations with reduced capabilities could be hosted on alternative computers.

7.2 System Structure

Four Integrated Computers form the core of the avionics system, connected with the peripheral equipment, including sensors and effectors, and displays and controls, and also the safety-critical Stores Management System.

The Integrated Computers perform the following roles:

- Interface and Monitoring Processor
- Mission Management System
- Communications Processor
- Defence, Attack and Armament Computer.

The structure of the avionics system is shown in Figure 6 below. The equipment shown in grey is external to the avionics system.

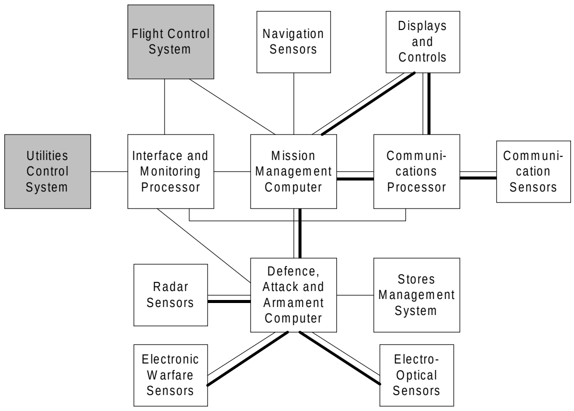


Figure 6: Example Avionics System Structure

Due to the high level of integration within the Integrated Computers, the data transfer loading between the individual equipment remains relatively moderate. Data transfer between equipment takes place either as in a conventional system via a Command / Response or Data Distribution Bus (eg. Mil-Std 1553 or ARINC 429), or by the use of a supplementary Fibre Channel overlay network, which is indicated by the broad lines in Figure 6. The latter provides for higher data rates between particular equipment, where these are required, for instance between the integrated computers, and for video data.

Interchangeability between the various Integrated Computers could be provided by the use of multiple instances of the same computer design. This should in principle be possible, due to the similarity of the requirements for the various system computers.

8 THE PATH FORWARD TOWARDS IMA

8.1 Further Development of the MMS

The Mission Management System defined in this paper represents a significant step towards implementing an ASAAC IMA architecture, a goal which is to be achieved with the introduction of the IMA hardware modules. There would, however, be a number of potential advantages in further developing the MMS concept by adding additional IMA features before progressing to a definitive IMA system:

- Multiple instances of Integrated Computers similar to the Mission Management System could be integrated in an avionics system, as shown in Sec. 7. The implementation of the ASAAC system management concept could be extended incrementally to encompass system-level management, so that such functions as initialisation and reconfiguration would be performed on a system-wide basis.
- A form of design-time blueprints could be implemented, containing resource requirements and specifications, to provide system design support.
- When available, the ASAAC network technology could be introduced, to provide the required high capacity, real-time deterministic behaviour, and network redundancy.
- Signal processing capability might also be added to the MMC, following the IMA strategy of centralising processing in the core.

8.2 Migration to an IMA Implementation

The eventual implementation of a system with ASAAC IMA modules will result in fundamental efficiency advantages for system development and operation, due to the use of a standardised, interchangeable hardware set.

The example system implementation presented in Sec. 7, based on the use of four Integrated Computers, represents an architecture which could be migrated to a full ASAAC IMA architecture, by the replacement of each of the Integrated Computers by an IMA Integration Area.

The use of individual modules will improve the hardware efficiency of reliable system designs, by permitting system reconfigurability at the module level. This represents a significant improvement, when compared with non-modular equipment such as the MMC, which is integrated as a complete unit, and which is therefore potentially susceptible to single point failures.

8.3 IMA Certification Considerations

Systems such as the Mission Management Computer that are based on IMA principles introduce a number of new factors, including in particular their reconfigurability, which are likely to affect their certification.

With traditional systems, certification has been achieved for the complete system, including both its hardware and its software. Some systems have implemented a degree of reconfiguration, but with a relatively restricted number of configuration cases, all of which have usually been designed into the system together with the hardware and application software, with the system being certified as a whole.

In contrast, in the ASAAC IMA system, and in the MMS, the hardware, operating system layer software and application functions are to be developed separately, with well-defined interfaces, and configurations determined for the integrated system.

The system configurations of the MMS are deterministic, in that all possible configurations are determined at design time, and stored in the blueprints. The total number of system configurations may however be very high, as the overall system configuration is made up of all the individual processor configurations, and as the processors are configurable at the level of individual processes.

While it will be necessary to certify each system configuration, it will not be practical to verify in detail the complete correct operation of an integrated ASAAC IMA system in all possible modes. This leads to the proposal to adopt a new approach and perform certification incrementally using a component-based method, as discussed below.

8.4 Incremental Certification

The basic principle of the incremental certification approach is to be able to modify a certified system, and to achieve certification for the modified system by certifying only the changes, without having to repeat the full certification process anew on the modified system in its entirety.

In order to be able to perform incremental certification, it is necessary to constrain, and to be able to identify, the effects of the modifications on the original certified system. In this way, the certification process for the modified system may be concentrated on the changes introduced and their resulting consequences.

Incremental certification can be applied to the development of completely new systems, by performing certification of the system at various stages in its development, as well as to the modification of in-service systems: the incremental certification approach is particularly applicable to the addition of application functions to an existing system.

The principle of incremental certification may be further developed to include component-based certification. Here, the basic principle is that each component is certified in its own right, so that when a system is assembled out of a number of components, it is then just the integration of the components which needs to be certified.

8.5 MMS Incremental Certification

It is proposed to adopt a component-based incremental certification approach for the Mission Management System. The main characteristics of the Mission Management System which support incremental certification are application portability together with the related technology transparency. These characteristics are derived primarily from the use of the APOS, the Application to Operating System layer interface. Due to the definition and standardisation of this interface, the Application

Functions are decoupled from the underlying operating system, hardware and drivers, which in turn enables the certification of the components either side of the APOS to be decoupled.

The adoption of incremental certification will require the development of an appropriate certification process by the certification authorities, and it is proposed that the MMS be used as a vehicle for development work on such a process.

When applying the principles of component-based incremental certification to the development of the MMS, there are a number of steps which may be taken to ease its certification.

Firstly, the application functions, in particular for the first MMS implementation, should be of a low criticality. In view of this, those that have been selected for the MMS are non- safety-critical, and do not require fail-safe implementation due to reliability considerations.

Further, due to the concerns regarding the certification of reconfigurable systems discussed above, it might be advisable to limit the scope of the reconfiguration mechanisms implemented in the MMS, in order to ease the first certification. One potential measure would be to limit the configurations to a small number, so that each reconfiguration step could be examined in detail. A further measure would be to exclude all fault-triggered reconfiguration, leaving only reconfiguration on mission mode changes. Once initial certification was obtained, the scope of the reconfiguration could be successively extended.

9 CONCLUSIONS

The Mission Management System described in this paper and being prototyped at ESG has been seen to feature an effective IMA-derived architecture, and to offer a representative set of mission management functions.

Through the adoption of the IMA principles from the ASAAC programme, and their implementation using COTS components on the basis of an open system architecture, the Mission Management System is able to offer the following key characteristics:

- Application portability is achieved by the application functions’ use of the APOS interface.
- Hardware independence is provided by hardware abstraction, and provides protection against component obsolescence.
- Reduced development time and lower costs are supported by the use of COTS components and methods.

A number of further valuable properties are also realised:

- System reconfigurability is provided by the system management function and blueprint data, and supports the optimisation of the use of the hardware resources.
- Fault tolerance is achieved by means of system reconfigurability, and improves system reliability.
- System growth and the ability to apply the system to aircraft for a wide range of roles are supported by the use of an open system architecture.
- Network independence is provided by the use of the NII, and permits the upgrading of the network technology.
- Software technology transparency is supported by the standardisation of the APOS interface to the operating system at a level above the underlying COTS operating system.

The development of the Mission Management System as a transitional architecture implementing mission management functions should achieve a major step towards the implementation of IMA systems, and provide valuable experience for their consequent implementation and certification. In accordance with the proposed incremental certification approach, the Mission Management System is open to progressive development to incorporate further aspects of the ASAAC IMA concepts, so supporting the eventual migration to a true IMA system.

In conclusion, it is hoped that development of systems based on transitional architectures, and particularly the Mission Management System presented in this paper, will significantly ease the introduction of Integrated Modular Avionic systems.

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Ref. 5 Avionics Architecture Standards as an Approach to Obsolescence Management, D.J. Jibb, J.B. Walker, NATO RTA System Concepts and Integration Panel Symposium, Budapest, Oct. 2000.

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11 ABBREVIATIONS

A/C	Aircraft
APOS	Application to Operating System Interface Layer
ARINC	Aeronautical Radio Inc.
ASAAC	Allied Standard Avionics Architecture Council
ATR	Air Transport Racking
BIT	Built-In Test
BSP	Board Support Package
COTS	Commercial Off-The Shelf
CU	Communications Unit
DPU	Data Processing Unit
EUCLID	European Co-operation for the Long Term in Defence
FC	Fibre Channel
GP	Graphics Processor
GPU	Graphics Processing Unit
GSM	Generic System Management
I/O	Input / Output
IMA	Integrated Modular Avionics
Mil Std	Military Standard (US)
MMC	Mission Management Computer
MMS	Mission Management System
MMU	Mass Memory Unit
MOS	MSL to Operating System Interface Layer
MOTS	Military Off-The- Shelf
MSL	Module Support Layer
NII	Network Independent Interface
OpenGL	Open Graphics Language
OS	Operating System
OSL	Operating System Layer
PCI	Peripheral Component Interconnect
PMC	PCI Mezzanine Card
POSIX	Portable Operating System Interface
RM	Resource Manager
RTBP	Run-Time Blueprints
RTOS	Real-Time Operating System
RTP	Research and Technology Programme
SBC	Single Board Computer
SM	System Manager
SMBP	System Management Blueprint Interface
SMOS	System Management to Operating System Interface Layer
TC	Transfer Connection
VME	Versa Module Europe

Avionics Architecture Standards as an Approach to Obsolescence Management.

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1 Summary

Obsolescence management techniques can be categorised as either production engineering based techniques that attempt to control an existing situation or design based approaches that attempt to minimise the initial problem. This paper addresses system architecture design as an approach to obsolescence management. The work of the ASAAC programme in developing open architecture standards designed to exhibit a high level of obsolescence robustness is described. Other issues that relate to the financing and organisation of obsolescence management are also discussed.

2 The nature of the problem

Component obsolescence increasingly affects our ability to maintain military avionics in service or even to maintain production capability. The electronic component industry is now almost entirely driven by the computer, commercial telecom and consumer electronics markets. The military market is much less than 1% of the total electronics market and at this level it is no longer able to finance the high technology plants and processes that are the needed to produce specific military grade versions of state of the art commercial components. Military platform lifetimes of 30 to 40 years are, if anything, tending to increase and already are an order of magnitude higher than the typical commercial processor chip lifetime of some 2 to 3 years. The decline of the military grade component market, coupled with the rapid pace of component technology development, now requires us to find ways of using commercial quality and commercial temperature range components in military systems.

The ownership of the obsolescence problem by the whole industry and customer community will be increasingly necessary. The basic issue of obsolescence is not new. Equipment designers have been faced with the problem of making the right component choice for many years and strategies for predicting the timing of component obsolescence, and limiting its impact, are generally well developed in the avionics industry. The fundamental issue is an economic one and put very simply it is that the cost of maintaining a capability is not zero! In the past equipment suppliers have been expected to maintain a supply of components over the life of a platform. Increasingly the rate of component obsolescence is preventing this.

The Weapon System user will wish to maintain platform effectiveness in response to changing threats. Indeed it is normal for the end user to want to enhance the Weapon System through the incorporation of new or improved capabilities. Such Weapon System upgrades can provide an ideal opportunity to also manage obsolescence! In the past Weapon System upgrades were based on the mid-life update or MLU. However in today's more stringent economic climate, evolutionary upgrades based on reuse of the existing design, especially the software application designs, make more economic sense. These incremental updates spread the cost of the update programme over time and are now generally favoured. In some cases such upgrades can actually become self-financing especially if older more expensive hardware can be replaced with fewer items that conform to a newer, more capable but less expensive standard.

The funding of the obsolescence problem will require significant changes in the way we do business. In the military avionics systems of the future most of the system functionality, and in consequence the major part of the design intellectual effort, will be resident in the software. Indeed the concept of modular avionics is to standardize the hardware content, and with increasing COTS usage the hardware will come to represent relatively low value in procurement terms. However the intellectual effort needed to create the overall avionics system is likely to be greater, not less than before. To sustain the design teams needed to develop and maintain future systems it is necessary that the major deliverable, that is the software, should attract profit levels over the life-cycle which are comparable in value to those which have to date sustained the hardware based avionics industrial competence. Arguably an avionics business based solely on the supply of boxes will not be viable in the long term. Instead the industry must evolve towards capability based partnerships with emphasis on maintenance of capability on the one hand in return for maintenance of realistic margins through the supply and updating of hardware and software systems.

Producing systems with highly interactive functions and less tangible boundaries than have been customary calls for close cooperation between avionics systems suppliers and the overall system integrators or airframe manufacturers. A whole new project structure is required, in which risks can be shared and specialist knowledge pooled across a horizontal organization very different to the pyramid approach used today.

Paper presented at the RTO SCI Symposium on "Strategies to Mitigate Obsolescence in Defense Systems Using Commercial Components", held in Budapest, Hungary, 23-25 October 2000, and published in RTO MP-072.

The "integrated product team" concept, combined with team-based incentives and goals is one method of achieving the necessary critical mass of skilled and motivated design intellect.

3 Production Engineering approaches to obsolescence management

The basis of what we shall call the production engineering approach to obsolescence management is to be found in the familiar component engineering and purchasing disciplines. Specialist Component Engineers will be involved in the initial component selection process and will analyse the proposed component lists from the point of view of obsolescence so as to identify single source items or items predicted to have short commercial availabilities. For these items a stock holding and purchasing plan might be employed based on lifetime buys, or alternatively on continuous monitoring of the component availability together with last time buys as and when necessary. Increasingly the Component Engineer will be supported by access to industry component databases and in the case of a large project may exchange component availability data with other companies also involved in the programme.

Given knowledge of the exact production quantities and time-scales it should be possible to guarantee sufficient stock is held, or can be obtained, to meet the build and life-time support requirements with minimum (but not zero) financial outlay. Of course a great many circumstances can upset this ideal situation so that the stock fails to match the production build and support levels. Increased scrap rates, field failures or simply additional orders can all become problems. Again ultimately this is a financial issue since with unlimited funds sufficient stocks could be held for almost any eventuality! If all else fails the final resort is to redesign the affected assembly at the lowest level where interchangeability can be achieved so as to minimise any necessary re-qualification costs.

This paper describes a complementary approach to obsolescence management concentrating on the initial definition of the system architecture. The paper describes the work of the ASAAC programme in developing open architecture standards designed to exhibit a high level of obsolescence robustness.

4 System Architecture as an Approach to Obsolescence Management

One of the ways to break the dependence of systems on specific COTS technologies is to design systems with so called Open Architectures that provide “loose” coupling between the avionics applications and the underlying infrastructure of the computing platform. This “loose” coupling requires standardised interfaces between the application software and the hardware, system software and network interconnects so as to provide the required software portability. In addition to the software interfaces other interfaces are required to provide technology transparency in the mechanical, power distribution, network and management aspects of the system. The term System Architecture refers to a consistent set of such interfaces and the associated hardware and software building blocks. By carefully choosing the building blocks set and associated interfaces it is possible to define a stable avionics infrastructure that can potentially be maintained over the life of a platform. The design of these interfaces and building blocks is the main objective of the Allied Standard Avionics Architecture programme ASAAC. The ASAAC programme was originally set up to take benefit from the life cycle cost savings and enhanced performance potential of Integrated Modular Avionics. Given the design issues that are raised by more integrated systems, the desire to use COTS and the required long platform lifetime it is no surprise that the ASAAC architecture concepts directly result in a system architecture that is inherently more robust with respect to component obsolescence.

5 ASAAC Project

The ASAAC Phase II Programme is sponsored by the MoDs of the UK, Germany and France through a tri-lateral Memorandum of Understanding that provides for a programme to define a set of STANAGs for military core avionics. The first draft of ASAAC standards was issued in February 1999 and the current phase of work, which began in December 1999, is a 45-month programme to demonstrate and validate the standards. The remainder of this paper describes the major goals of the project and gives an overview of the top-level requirements derived from those goals. Each architecture concept area comprising software, packaging, networks and system management is described together with a short description of the relevant standards.

5.1 ASAAC Architecture Goals

The prime objective of ASAAC is to define a flexible avionics architecture that will balance affordability constraints with combat capability and combat availability. When completed, the architecture will be captured in a set of military standards (STANAGS) for IMA systems.

The three principle goals for ASAAC are,

- **Reduced Life Cycle Cost**

A major objective is to reduce the accumulated costs over the life cycle of a system i.e. the acquisition and support costs.

- **Improved Mission Performance**

The system must be capable of fulfilling the missions asked of it and satisfy all possible airborne platforms in terms of functionality, capability, accuracy, configurability and interoperability under the full scope of operating conditions.

- **Improved Operational Performance**

The goal adopted is that the system must achieve a combat capability of 150 hours (equivalent to 30 days) without maintenance with an availability of at least 95%. This goal far exceeds that achievable today and an

ASAAC system will be required to exhibit fault tolerance so that it can survive the occurrence of faults with a required level of functionality.

In addition, the maintenance philosophy dictates that modules of the system must be interchangeable between platforms of the different NATO nations and replaceable at first line.

5.2 Requirements

ASAAC has established a set of top-level requirements for an avionics architecture that are derived from the three major drivers described above. The required output from ASAAC is a set of standards for military avionics. To define those standards, ASAAC first defined a set of concepts, which described the functionality expected of a future avionics system, covering all aspects of the system from software through to packaging. From these concepts, the nature and specification of the necessary interfaces were derived. These interfaces include physical standards, software interfaces and architectural descriptions.

The top-level requirements established by ASAAC are as follows:

1. Small Set of Common Modules

The set of common modules should be reduced to a minimum to reduce development and support costs.

2. Modules Applicable to Wide Range of Platforms

The architecture should be able to support the needs of a wide variety of airborne platforms. The architecture must therefore be scaleable to be applicable to a wide range of different platforms.

3. Re-use of Software

The reusability of software between the different computational elements should be maximised.

4. Modules Replaceable at 1st Line on Aircraft

The system must be designed such that the modules can be removed at the operational site for replacement.

5. No Base and Depot Level Maintenance

The combat dependence of a platform on fixed-site airbases should be reduced or eliminated

6. Deferred Maintenance/Fault Tolerance

The architecture shall have sufficient fault tolerance to enable the system to be restored, to a predetermined level of capability, in the event of a fault at least until the next scheduled maintenance event.

7. Comprehensive BIT and Testability

The architecture shall not require tools at 1st line and shall allow on-aircraft maintenance.

8. Interoperability

Separate elements of the architecture shall inter-operate with each other.

9. Interchangeability

This requirement relates to the ability to interchange any element with any other separately developed architecture element of the same generic function.

10. Technology Transparency

The architecture should not rely on technology specific implementation techniques.

11. Use of Commercial Components, Technologies and Processes

The architecture should be designed in such a manner as to maximise the potential use of commercially available hardware and software products.

12. Maximise Digital Processing of Functions

The architecture should support the maximum amount of digital processing.

13. Functional and Physical Integration

It should be possible to attain a high level of functional integration across a physically integrated platform. This requirement aims to promote the abstraction of software applications from hardware in order to allow applications to be mapped onto various hardware architectures.

14. Open System Architecture

The architecture should exploit open commercial standards having a high-perceived level of longevity.

15. Growth Capability;

The ability to incorporate growth in technology performance and application requirements over the life of the system.

16. Modularity and Configurability;

The ability to partition a system into separate elements, each of which is individually replaceable.

In addition to these top-level requirements, a number of technical requirements were specified to ensure the usability of an ASAAC system. These requirements covered areas such as certification and qualification, security, system management and environmental requirements.

5.3 ASAAC Concept Overview

This section will provide an overview of the concepts and standards currently under definition. It is possible, and, in fact, highly likely, that the concepts will change during the programme as a result of the experience gained. All of the concepts in ASAAC are highly integrated and because of this there are numerous dependencies that make it difficult to describe the concepts clearly in a sequential manner. The software concept constitutes the most important area within ASAAC and it has therefore been described first, the other concepts following in an arbitrary order. Throughout the text there are several references to concepts that are defined in more detail later in the paper.

5.3.1 ASAAC Software Concept

The ASAAC software architecture concept defines a three-layer architecture, based on the philosophy shown in Figure 1. This philosophy describes three layers,

- **Application Layer (AL)** – representing the applications that are specific to a particular aircraft

or platform, but are independent of the enabling hardware.

- **Operating System Layer (OSL)** – representing the system software usable across all aircraft types and on all hardware architectures.
- **Module Support Layer (MSL)** – representing the hardware specific software that allows the upper software layers to be hardware independent.

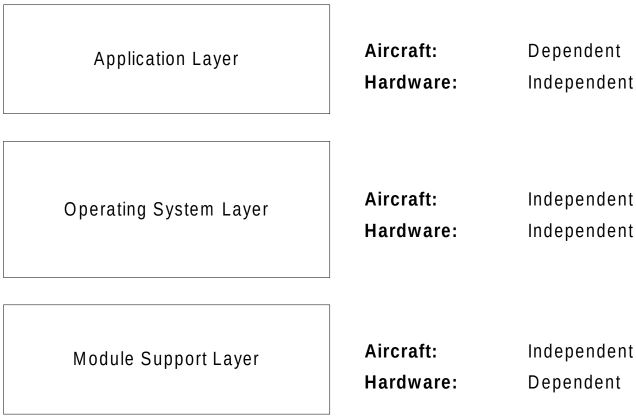

Figure 1 Software Architecture Philosophy

This philosophy requires the definition of two interfaces, as shown in **Figure 2 Software Interfaces**. These are the:

- **APOS** – the Application to Operating System interface and the
- **MOS –** the Module to Operating System interface

These interfaces provide the independence for each of the layers described previously. In addition to these layers, three functional concepts viz. Generic System Management, Blueprints and Virtual Channels were defined.

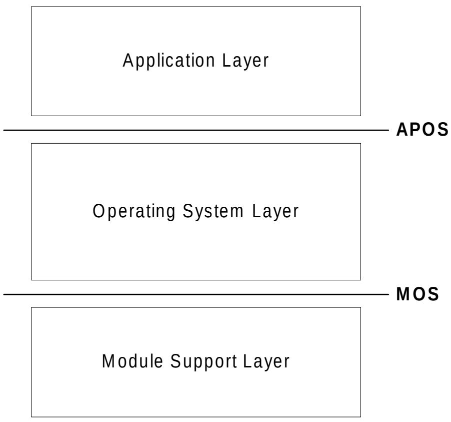

Figure 2 Software Interfaces

- **Generic System Management Concept**

The system management of an IMA system can be split into two distinct categories,

- **Application Management and**
- **Run-time System Management.**

Applications Management involves, for example, mission selection and controlling the moding aspects of a system i.e. which applications/processes need to be active during a given phase of flight. This category is implemented by the **Application Manager (AM)** located in the AL. Run-time System Management refers to controlling system initialisation and shutdown, configuration and reconfiguration, fault management, interfacing with blueprints and application scheduling. This category is implemented by the **Generic System Manager (GSM)** located in the OSL. The GSM comprises four functional elements; Health Manager, Fault Manager, Configuration Manager and Security Manager. The nature and operation of the GSM and these elements are covered in more detail in section 5.3.4.

- **Blueprint Concept**

In order to support application re-use across different hardware technologies and architectures the concept of Blueprints configuration files has been defined. Blueprints describe the mapping between the resources required by an application, in terms of processing power and communication requirements, to the available resources provided by the hardware. They are realized as a database directly accessible by the GSM. Blueprints are covered in more detail in section 5.3.1.1.

The final software architecture incorporating these concepts is shown in Figure 3. The Operating System and Extensions block includes both the operating system required for scheduling and task prioritisation purposes and other functional elements such as the Virtual Channel Manager to support communications within the system.

This software architecture requires the definition of the following interfaces,

- **SMOS –** the System Manager to Operating System interface
- **SMBP** – the System Manager to Blueprints interface and the following logical interfaces,
- **OLI –** the Operating System Logical Interface
- **MLI –** the Module Support Layer Logical Interface
- **GLI –** the GSM Logical Interface

These interfaces are described in more detail in section 5.3.1.2 Software Interface Definitions.

- **Virtual Channel Concept**

Virtual Channels (VCs) are a message-based means of communication between processes. They are designed to support the abstraction of application communication from hardware implementation. VCs are predictable in operation. In other words, an application can depend upon a VC to provide a certain set of performance characteristics, for example defined latency or bandwidth. VCs support one-to-one and one-to-many communication topologies. Other topologies, such as many-to-many, can be implemented using these two basic mechanisms. If a process on one processor needs

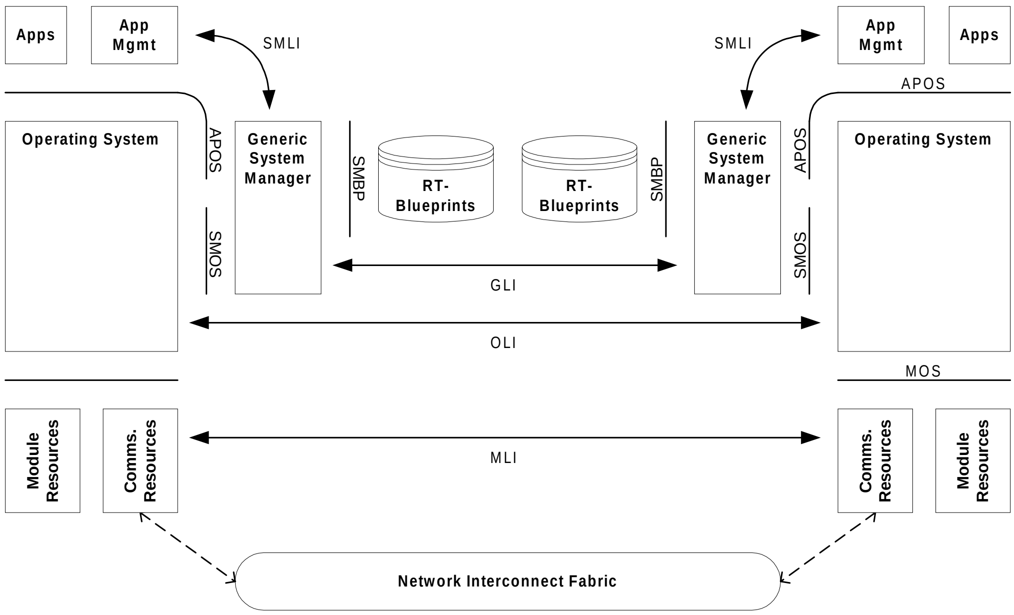

Figure 3 ASAAC Software Architecture

to communicate with a different process on the same processor, shown as type I in Figure 4 Virtual Channel Operation the communication configuration and eventual message handling are carried out by the Virtual Channel Manager (VCM) resident in the OSL. For communication between processors on the same module and on different modules, shown as types II and III respectively in Figure 4 Virtual Channel Operation, a routing service within the MSL must assist the VCM in ensuring correct transmission of the data.

5.3.1.1 Blueprints

Blueprints contain the information that defines the mapping of application processes onto the functional modules. In order to operate, the system will require a number of certified functional configurations. A functional configuration in this context refers to a mapping of application processes to module processors. These configurations will be specified at design-time and verified against the constraints placed on the system. The set of allowable configurations will be stored within the system and referenced at run time. A choice between the certified configurations will be made depending upon factors such as fault occurrence, mission status etc. In the event of a detected and localised fault or a mode change request, a reconfiguration will be performed by first selecting and then instantiating the most appropriate new functional configuration.

5.3.1.2 Software Interface Definitions

The following interfaces are defined in the software concept:

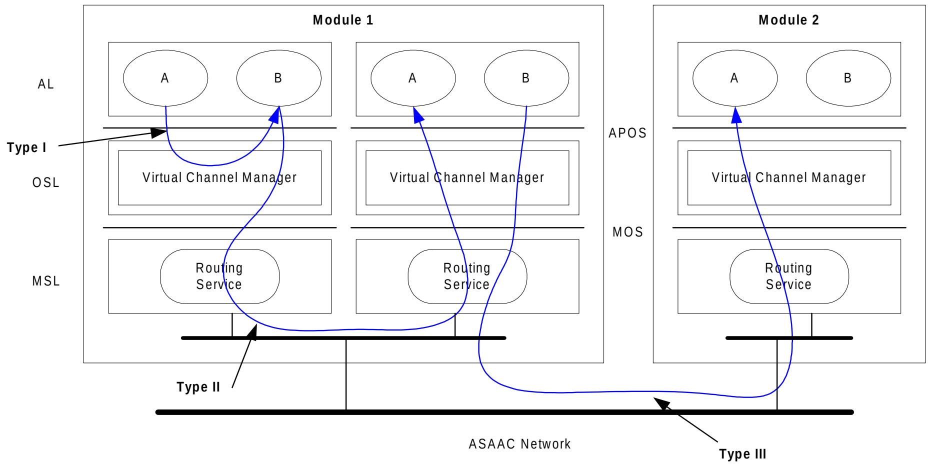

Figure 4 Virtual Channel Operation

- **APOS** – Application to Operating System

This interface is split into two sections; the Core APOS and the Specific APOS. The Core APOS applies to all module types, whereas the Specific APOS contains services specific to a particular module type.

At present, the Core APOS contains services for Virtual Channel communication, process synchronisation, timer handling, fault reporting, application management and thread management.

The Specific APOS contains services for the Graphics Processing Module (GPM), Mass Memory Module (MMM) and Power Conversion Module (PCM).

- **MOS** – Module Support Layer to Operating System

The purpose of the MOS interface is to isolate the system management software and operating system from the underlying hardware. It is envisaged that the system management software and operating system will have to be certificated and that it will be impractical to have to repeat this operation every time the hardware changes. Compliance with the MOS standard interface will allow for reuse of the System Management software and it is expected that this will minimize the need for rectification of the system management software. However it is also recognized by ASAAC that COTS OSs will exist that do not comply with the MOS. To allow these COTS products to be exploited in situations where it is not essential to preserve the integrity of the system management software ASAAC allows the use of the MOS to be optional.

- **SMOS** - System Manager to Operating System

This interface allows the GSM to access the MOS services for network configuration, process management, etc. as well as providing standard OS services.

- **SMBP** - System Manager to Blueprints interface

This interface allows the GSM to access the run-time Blueprints in order to manage configuration during system operation.

- **SMLI** - System Manager Logical Interface

This interface allows the AM to specify what application configuration is required and notify the GSM of the reconfiguration request.

- **GLI -** GSM Logical Interface

This interface specifies the message format allowing GSMs in the system management hierarchy to communicate with each other. VCs are used to transfer the messages.

- **OLI** - Operating System Logical Interface

This interface includes specification of the data presentation format to allow different operating systems to communicate with each other. Standard formats are also included for VCs and file management.

- **MLI** - MSL Logical Interface

This interface describes the network protocol and message formatting necessary for low-level communication.

5.3.1.3 Software Implementation

Although software implementation will not feature in the ASAAC standards, it is useful to give an overview of the implementation methods considered in the definition of the standards. A significant influence on the choice of software implementation in ASAAC is that of module interchangeability. This requires the ability to remove one module and replace it with another of the same generic type possibly of different implementation technology and from a different manufacturer. At present, it is expected that the common code to be executed on the modules within an ASAAC system will be stored in a central location, the Mass Memory Module (MMM). Therefore, if modules are to be interchangeable, one of the following software implementations has to be chosen,

- Produce a single binary image for every processor on every module.
- Use a Virtual Binary Interface (VBI). This is a run-time interface where executable code can expect certain functions to be resident at standardised locations in the processor memory map.
- Use an interpreted language such as Java. This would provide the ultimate in portability in that the code, at the byte-code level, would be completely reusable across any implementation of the Java (or other language) virtual machine. However, technology in this area is in its infancy and efficiency is not considered at a level suitable for avionics systems.

5.3.2 Common Functional Modules

An IMA system will consist of racks populated by Line Replaceable Modules (LRMs). One aim of ASAAC is to define a set of line replaceable Common Functional Modules (CFMs) that will be applicable to all ASAAC compliant IMA systems. Because an ASAAC module is line replaceable, it must have well defined physical and logical boundaries. ASAAC is tasked with defining the interfaces at these boundaries; in the physical sense, it is the **Module Physical Interface (MPI)**, and in the logical sense, it is the **Module Logical Interface (MLI)**.

ASAAC does not standardise on the architecture or internal interfaces within a CFM. ASAAC instead specifies two major areas of expected functionality for each module covering processing-specific and system-level functionality. The processing-specific functionality is covered by a set of requirements for each CFM type. The CFM System Support standard encompasses system-level aspects such as the system booting procedure, PBIT operation and OS download.

It is desirable for the module set to be small in size in order to maximise the potential savings in life-cycle costs. However, the task of standardising different types of processing and functionality is not simple; abstraction of the complex nature of modern technologies and dealing with differences in architectures and designs is extremely problematic.

In ASAAC, six different CFM types have been defined,

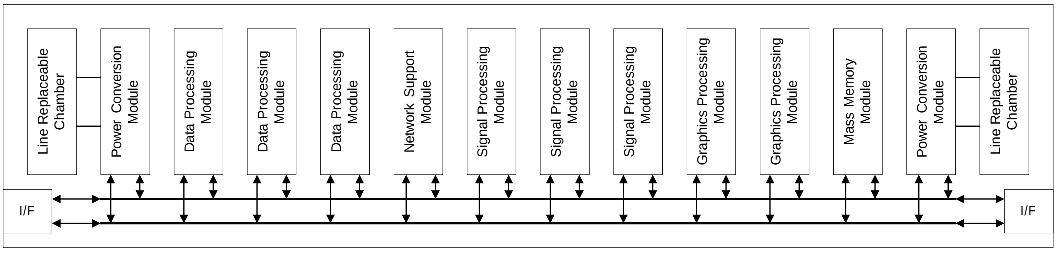

Figure 5 ASAAC Rack Arrangement

- **DPM – Data Processing Module**

The DPM covers the data-dependent data processing activities expected of the IMA system.

- **SPM – Signal Processing Module**

The SPM covers the data-independent processing activities of the IMA system, such as DSP based front-end signal processing.

- **GPM – Graphics Processing Module**

The GPM provides symbol-based graphics generation and image composition and formatting.

- **MMM – Mass Memory Module**

ASAAC promotes the use of a central facility for program storage for portable code. In addition, IMA systems have a large non-volatile storage requirement for capabilities such as terrain information, EW information, mission planning etc.

- **NSM – Network Support Module**

The NSM provides the network upgradeability, in terms of protocol and/or network control, by locating the active components for the network within a line replaceable module.

- **PCM – Power Conversion Module**

The PCM acts as the first stage in a two-stage power conversion architecture converting raw aircraft power to 48V for distribution across an avionics rack backplane.

An ASAAC rack (see Fig 5) is expected to comprise:

- **A Single NSM,** to provide the network routing,
- **A Single MMM**, to provide initialisation control and program download,
- **Multiple DPMs**, as the general processing resource,
- **Multiple SPMs**, as the signal processing resource,
- **One or two GPMs**, as the graphics processing resource, and
- **Two PCMs,** to provide dual redundancy on the power inputs.

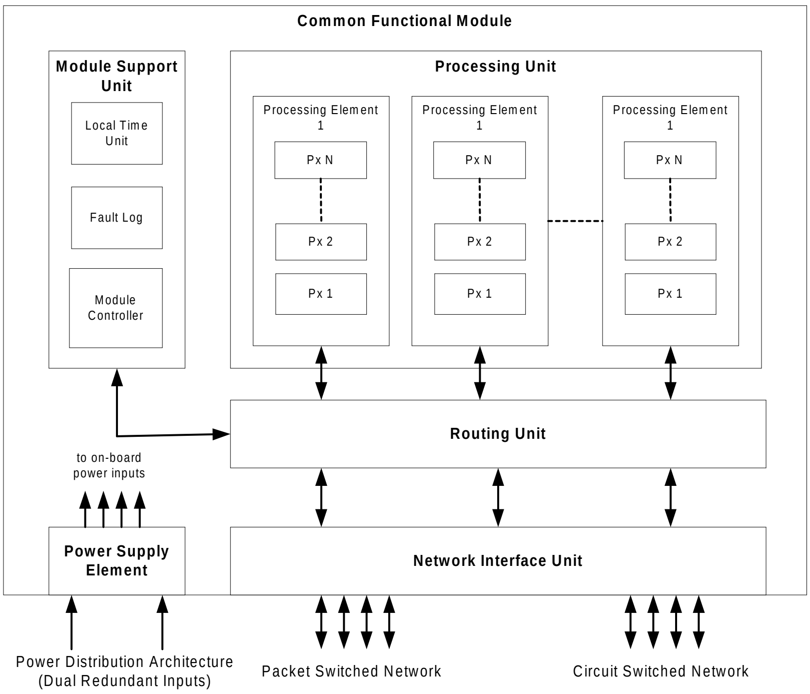

Figure 6 Generic CFM Architecture

5.3.2.1 Generic CFM Concept

The DPM, SPM, GPM and MMM module types outlined above adhere to the Generic CFM Concept shown graphically in Figure 6 Generic CFM Architecture. This concept was devised to promote re-use of hardware and software elements for module manufacturers. The Generic CFM Concept defines the following functional units:

- **MSU – Module Support Unit.**

The MSU is responsible for supporting certain system activities, specifically System Initialisation and Fault Management. The MSU also supports generic functionality required of each ASAAC-visible processor, i.e. one that executes the ASAAC software stack, such as time synchronisation and fault logging. The MSU contains a programmable resource, termed a Module Controller. Together with non-volatile memory used for status, BIT and fault logging. The MSU is also responsible for standard time distribution, which is covered in more detail in section 5.3.5.

- **NIU – Network Interface Unit**

Each module will interface to the standard ASAAC network through the MPI and MLI. Although each module type will likely have different network interface requirements, in terms of number of links and link capacity, a significant amount of the network interface should be common between module types assuming the same network. The NIU is responsible for acting as the primary network interface on the module and converts the on-board communications to the format required by the ASAAC network. The present network concept in ASAAC refers to a Packet-Switched and a Circuit-Switched network; these are covered further in section 5.3.3.

- **RU – Routing Unit**

The RU represents the internal communication within a CFM. The Routing Unit implies no architecture or implementation; it only describes the functional capability that allows all the other units to communicate with each other.

- **PU – Processing Unit**

The PU represents the processing specific functionality for each of the module types; data, signal, graphics processing or mass memory.

- **PSE – Power Supply Element**

48V is provided, as standard, to each module from the backplane. It is the responsibility of the PSE to convert this input to the voltage levels required on the module. Each CFM will have dual-redundant power inputs and the PSE shall be able to consolidate these.

5.3.3 Network

The networking requirements for IMA systems differ greatly from those of previous federated systems. The splitting of processing functions that were previously located within single units and the trend to higher digitisation rates give rise to a larger required total network bandwidth. In addition, the requirements that the system support fault tolerance demands that the network support a high level of mobility of software

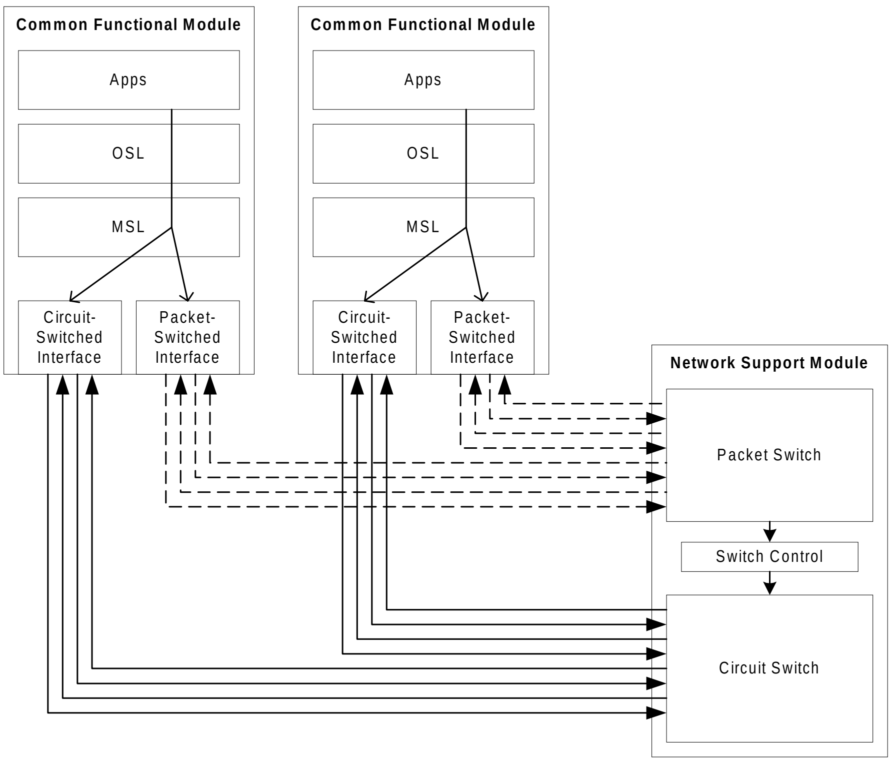

Figure 7 ASAAC Network Architecture

application functions within the physical system. The top-level requirement for module interchangeability implies that the communication network must provide standardised interfaces and operations. At the same time the network concept must support technology transparency and provide for the incorporation of COTS technology with potential for scalability and growth. A unified approach to the network for the whole IMA system is desirable in order to avoid the proliferation of hardware and software elements for different network types.

Parallel electrical bus technology is perceived to now be at an upper limit as far as the module interface is concerned. Serial protocols are very much preferred because of their routing and growth capabilities and because of the predicted transition from electrical to optical transmission media. Although optical media for module interconnection has still to be proven for extensive use in an avionics environment, especially the choice between single- and multi-mode technologies, it is almost inevitable that it will be fully adopted for IMA systems in the future. ASAAC has made the use of optical media mandatory for the standards demonstration and validation to be performed as part of the project.

The current baseline for the network describes two distinct network components viz.

- **Circuit-switched network** and
- **Packet-switched network**

These two networks make use of an NSM to provide the routing and link reconfiguration.

The circuit-switched network is implemented using unidirectional SDH STM-16 point-to-point links. This network is aimed for high-bandwidth data-streaming applications. The particular version of SDH used, STM-16, should provide a single link bandwidth of 2.488 Gbit/s. The NSM will contain protocol-independent switches to provide the routing.

The packet-switched network will be implemented using ATM on top of an SDH STM-4 physical layer. This network is aimed at the lower bandwidth applications requiring high routing flexibility. SDH STM-4 can be expected to provide a bandwidth of 622 Mbit/s. The NSM will contain the ATM switches necessary to provide the routing.

The interconnection architecture between modules using the NSM is shown in Figure 7 ASAAC Network Architecture Each module communicates via packet-switched and circuit-switched network interfaces. Any communication from an application is directed to the relevant interface by the MSL on the processor.

The standards relevant to the network are the

- **MPI** – the module physical interface to the network, and the
- **MLI** – the module logical interface to the network.

5.3.4 System Management

System Management builds upon the other concepts to allow an IMA system to operate. In ASAAC, the System Management concept does not relate directly to a standard however elements of the concept are implemented in other standards, such as the SMOS and CFM System Support. The majority of the concept is defined in the System Management Guidelines. In essence, the concept exists as a recommended method of implementation describing sets of functionality rather than as a set of interface standards.

System management must be able to control the configuration and operation of an avionics system at processor level, and at the higher rack or integration area levels. To achieve this, the system management concept in ASAAC follows a hierarchical approach, maximising the modularity and re-use of functional elements. The following levels of hierarchy are defined,

- Aircraft level
- Integration Area level
- Resource Element level

Bi-directional communication exists between the levels of system management to provide control and reporting paths that allow a coherent view of the system. The system management concept is implemented by the Generic System Manager (GSM) and Application Manager (AM) in the software concept. The GSM is resident within the OSL of the software stack and the AM within the application layer. The hierarchy is shown in Figure 8 System Management Hierarchy.

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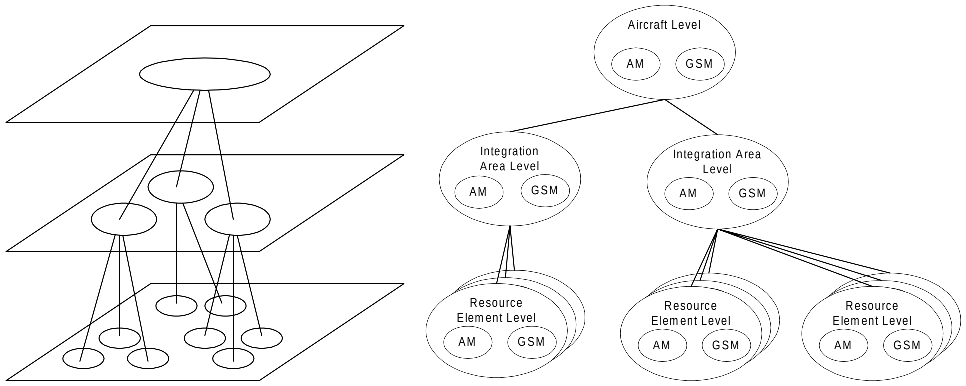

Figure 8 System Management Hierarchy

The GSM will contain the following functional elements,

- **Health Monitor (HM)** – This element is responsible for monitoring the health of the system. It receives input from the Fault Manager located in the next level down in the management hierarchy, as shown in Figure 9 GSM Interactions. After processing of the fault reports, it will indicate to the Fault Manager located in the same level of hierarchy if the HM believes a persistent fault to exist.
- **Fault Manager (FM)** – This element is responsible for collating fault reports from the HM and reporting to the HM in the management layer above. The FM then determines the action to be taken and makes a request for reconfiguration to the Configuration Manager. The nature of the request is dependent upon the nature of the fault report.
- **Configuration Manager (CM)** – This element is responsible for co-ordinating the requested reconfigurations from the FM. The CM in one level communicates with the CM in the lower level to manage the reconfiguration.
- **Security Manager (SM)** – This element performs fairly independently of the other elements and is responsible for control of access rights for input and output requests within the relevant management area, be it aircraft, integration area or resource element. The nature of security in an IMA system is covered later in this section.

A resource element is conceptually defined as the lowest level of the management hierarchy. In an implemented system, it is expected that each processor hosting an ASAAC software stack will be defined as a Resource Element.

For aircraft and integration area managers, a GSM on a processor or resource element within that area will be nominated as the area manager. This nomination occurs at system initialisation or if necessary after a reconfiguration resulting from a failure.

5.3.5 System Time

In order to synchronise the management tasks and applications within the system, it is necessary to maintain an absolute time clock that is available to all elements within the system. To achieve this, a Master Reference Clock (MRC) is used to distribute a time signal to Reference Clocks located on the modules.

5.3.6 Reconfiguration

The reconfiguration concept refers to the following definitions,

- **Configuration** – a static state of the system, with certain processes executing on certain processors.
- **Reconfiguration –** the set of actions that need to be executed to perform a transition from one configuration to another configuration.

There are two distinct situations where a reconfiguration will be initiated,

In the event of a mode change request – here the task is simple; the System State is known so the reconfiguration process to the required new configuration is known.

In the event of a fault – here the situation is more complex. If a fault has occurred, then the system is in an unknown state. This state must be analysed and verified before reconfiguration to a known configuration can be carried out. The present concept for reconfiguration is that all the possible (and relevant) configurations of processes on processors are stored in the blueprints. Upon initialisation or reconfiguration, the most suitable configuration is chosen from the Blueprints.

5.3.7 System Initialisation

The initialisation of the system occurs in three stages. First, a generic procedure is executed to provide a limited initial capability. Second a mission dependent

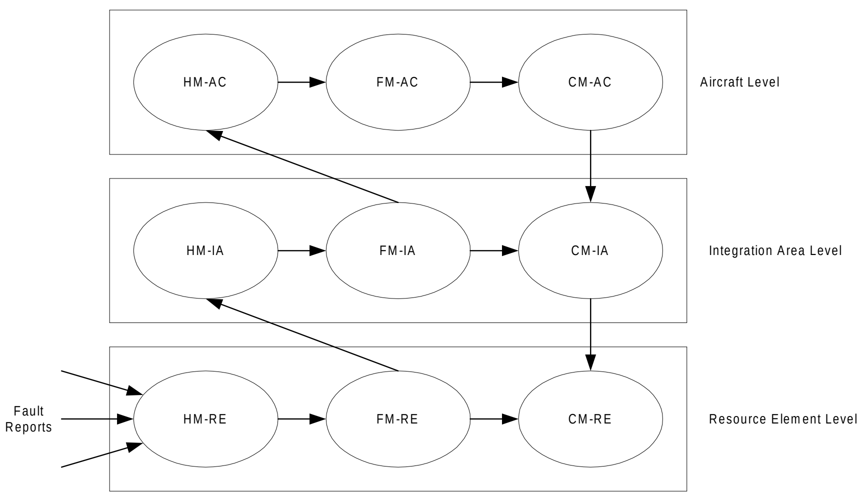

Figure 9 GSM Interactions

initialisation configures the system into partial operational mode to allow activities such as refueling and maintenance. Finally, a detailed mission-oriented initialisation configures the applications to provide the full avionics functions. These initialisations are essentially a sequence of reconfigurations that build up levels of functionality at each step. The present concept is to utilise a MMM as a 'bootstrap' module to initiate this process in collaboration with a DPM and an NSM.

5.3.8 Fault Management

Fault Management is the methodology of handling faults within a system in order to prevent total or partial system failure. It encompasses the following aspects,

- **Fault Tolerance (FT),** which allows continued operation of the system in the presence of faults
- **Integrated Test and Maintenance (ITM),** which allows identification of the failed component for repair.

FT has the further responsibility to ensure survival of the system with a suitable level of functionality in the event of a fault.

5.3.9 Security

In general, security is concerned with the protection of assets from threats where a threat is defined as the potential for abuse of the protected assets. Because of the highly integrated nature of an IMA system, functional areas with very strict security requirements such as communications and navigation are brought into close contact with other areas such as radar and vehicle management. IMA systems must, therefore, be able to deal with differing security requirements across common equipment and ensure sufficient asset protection. There are two major areas of security,

- **Communications Security (COMSEC)** – for COMSEC, a functional interface to a cryptographic functionality will be defined
- **Computer Security (COMPUSEC)** – for COMPUSEC, the functionality can be located either wholly in software or spread between hardware and software.

It is highly likely that compliance with the Common Criteria (CC) for Information Technology Security Evaluation will form part of the accreditation for an IMA system.

5.3.10 Safety and Certification

The key characteristics that an ASAAC system must demonstrate to support safety certification are data integrity, guaranteed availability of data and resources, and predictability of operation. The higher integration that is achieved through the use of IMA will mean that safety/certification issues, similar to security issues, will begin to affect a larger number of functional areas.

At this stage of the ASAAC project, the issues regarding security and safety and certification are not fully defined. Task forces are at present continuing to investigate the possible consequences that the various requirements will have on an IMA system and have yet to produce an agreed approach for recommendation.

5.3.11 Packaging

The physical outline and connector configuration of a module could be considered one of the most important aspects of an IMA system. For modules to be interchangeable at all there must be a standard physical interface. The ASAAC packaging concept defines the Module Physical Interface (MPI), which covers the packaging, cooling, power supply distribution, electromagnetic compatibility and interconnection standards.

5.3.11.1 Module Packaging

The ASAAC packaging baseline standard specifies a module format similar to Double Eurocard, termed ASAAC A. However, ASAAC A specifies a short-side connector as opposed to the long side for traditional VME. Where compatibility could be considered is in the usable area of a module. In that case, COTS board designs could be ported to the standard physical outline with greater likelihood of success. Because of the concept defined for the CFMs in ASAAC, there will be a minimum area suitable for providing the defined functionality. Also, the fact that CFMs are to be line replaceable implies that they should be of a certain manageable size. It is generally felt that Double Eurocard is approximately the correct area in which to provide a CFM with a significant capability.

5.3.11.2 Module Cooling

Two cooling techniques have been chosen for the present baseline,

- **Conduction cooling**, with the possibility to use heat pipes in the module core to enhance the performance.
- **Airflow cooling**, with air circulating either outside the CFM (air flow around), through a central CFM heat exchanger (air flow through), or with air directly on the module components (direct air flow).

These options are chosen to provide the widest range of alternatives between affordability and performance, thus catering for anticipated module power dissipation levels and different platform cooling systems.

- **Module Interconnect**

ASAAC only allows optical interconnections external to a module, except for power distribution. For optical interconnect, two technologies have been considered,

  - **Embedded Fibre** – the optical fibre is placed onto an adhesive coated substrate and an additional protective layer mounted on top. Complex topologies are possible, including star couplers.
  - **Polymer** – this technology is the fabrication of flexible flat sheets of polymer containing optical waveguides, which can be very cost-efficient if produced in large quantities.

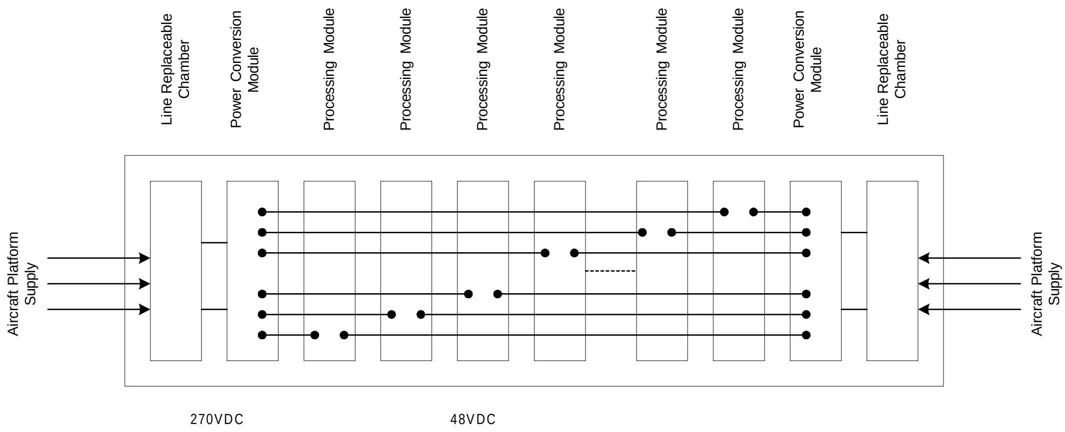

Figure 10 Power Supply Architecture

- **Module Connector**

ASAAC will define a connector shell capable of accommodating either butt coupled or free-space inserts. The connector shell consists of aluminium support shells, each shell having three main cavities. At each end of the module shell a polarised guide pin is positioned with the corresponding guide socket on the backplane shell. Each shell cavity can accommodate a variety of inserts; standard size 22 signal contacts, high density PCB signal contacts, size 16 power contacts and 32 or 48 fibre-optic contacts, depending on density. Therefore, a customisable connector can be manufactured that is tailored to specific system requirements.

5.3.12 Power Distribution Architecture

The power distribution architecture within ASAAC is a two-stage conversion process, with conversion from the aircraft platform supply to an intermediate internal rack voltage level, and subsequent conversion to logic voltage level at each module. A Line Replaceable Chamber (LRC) converts the aircraft platform supply to 270VDC and performs the supply filtering. The Power Conversion Module (PCM) converts the 270VDC supply to a rack standard of 48VDC. This scheme is shown in Figure 10 Power Supply Architecture.

48VDC was chosen because it is a common commercial standard and possesses inherent safety and support for hot plugging and unplugging of modules. Note that, in the architecture, each processing module has dual redundant supplies to enhance fault tolerance. Each processing module will perform on-board supply consolidation and conversion to appropriate logic levels.

The PCM will possess load current-monitoring capabilities in order to detect faulty power circuits on modules.

5.4 Standards Under Definition

The standards under definition by ASAAC are listed in Table 1.

Standard Name	Status
APOS	First draft available
MOS	First draft available
SMOS	First draft available
SMBP	First draft available
GLI	First draft available
OLI	First draft available
MLI	First draft available
CFM System Support	First draft available
MPI	First draft available

Table 1 List of ASAAC Standards

6 Conclusions

This paper has described the ASAAC Avionics Architecture that is being developed to provide the technical basis for advanced avionics for new platforms and updates from around 2003 onward. A carefully designed System Architecture can provide a stable structure within which COTS components and processes can be accommodated with reduced risk from obsolescence. The interfaces reduce the coupling between the application software, which is the major repository of value in the avionics system and the underlying hardware, software and network components. A system designed around IMA concepts will be much easier to upgrade and consequently more resilient to component obsolescence. Maintaining the capability of an avionics system in the future will entail regular expenditure on technology insertion activities that will provide benefits in terms of performance and at the same time will contribute to the management of component obsolescence.

SoC : Une nouvelle approche de l'amélioration des performances des systèmes pour combattre les problèmes de disponibilité à long terme

SoC : A New Approach to Enhance System Performances and to Combat the Long-Term Availability Issue

(janvier 2001)

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RESUME

Les applications militaires ayant perdu leur leadership dans le domaine de l'électronique, elles auront de plus en plus à utiliser des technologies civiles. Il faudra apprendre à les utiliser ou à les adapter à nos spécificités, par exemple faibles volumes en production, température de fonctionnement élevée… L'utilisation de ce que l'on a pris l'habitude d'appeler « composants sur étagère » continuera même si l'assurance de pouvoir les approvisionner sur le long terme est un souci non négligeable.

Mais une autre technologie, également issue du Civil, paraît prometteuse : Les « System on Chip » ou « SoC ». En d'autres termes, la possibilité d'intégrer dans un seul circuit ou des circuits en nombre réduit un calculateur complet, répondant, par exemple, à une application de pilotage / guidage pour missile. Cette approche est maintenant bien établie dans le monde civil et industriel tel que les télécommunications, mais encore relativement peu implémentée dans les systèmes de défense.

Il s'agit en fait d'une technologie ASIC (Application Specific Integrated Circuit), mais intégrant jusqu'à plusieurs millions de portes. Pour pouvoir maîtriser la complexité de la phase de conception en terme de coût et de délais, les SoC sont largement basés sur la notion de réutilisation de blocs fonctionnels : les « Intellectual Properties » ou « IP ». En fait, ces IP ne sont rien d'autres que des composants sur étagère mais virtuels, donc indépendants d'une quelconque technologie. Ils peuvent soit achetés soit être issus de conceptions précédentes. Les avantages sont nombreux, par exemple :

- Il est possible de concevoir le SoC sur la gamme de température voulue.
- En cas d'obsolescence d'une technologie, la société utilisatrice étant propriétaire de la définition du circuit peut migrer vers une technologie plus récente…

Certaines difficultés restent, bien entendu, à surmonter tel que, et de manière non exhaustive :

- L'accès aux fonderies, en cas de sélection d'une technologies ASIC (par opposition à des Programmable Logic Devices : PLD) du fait des faibles volumes ;
- La durée des plannings de développement ;
- Le coût des composants virtuels.

Tous ces points sont passés en revue dans ce document.

INTRODUCTION

L'évolution des marchés Militaires

L'utilisation de concepts civils pour des applications militaires est une tendance qui peut déjà être constatée et qui va sûrement s'amplifier. Une telle démarche n'est bien sûr pas sans conséquences. L'une d'elle – très positive – consiste à écrire des Spécifications Techniques de Besoin souvent mieux dimensionnées par rapport aux besoins réels. Toutefois, certaines contraintes perdureront comme le besoin de pouvoir fonctionner dans des environnements difficiles. Il n'y a, en effet, aucune raison que les profils et théâtres d'opération des missions militaires changent. L'élévation de température peut aussi être due à un échauffement cinétique (exemple : un missile en vol libre). Même si on peut s'attendre à des progrès dans la gestion des calories, cela ne changera probablement pas radicalement le problème au niveau des composants électroniques.

Il faut noter l'impact que peut avoir la permanente diminution des lithographies, diminution qui peut engendrer d'autres phénomènes (SEU : Single Event Upset).

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L’utilisation de concepts civils

Le sujet peut être abordé sous deux aspects.

Choix de standards / protocoles et d’éléments d’architecture de systèmes et de calculateurs civils : C’est le 1ier aspect. Pendant la tâche d’architecture, un concepteur peut ainsi sélectionner un ou plusieurs standard(s) (exemples : USB, IEEE 1394, PCI…). Il bénéficiera ainsi du support de la très large communauté utilisatrice : existence de la norme, des outils, des composants (virtuels et réels, attention au risque de pérennité pour ces derniers)… Même s’il décide de n’utiliser qu’une partie de ce dont il peut disposer, il sera largement gagnant en terme de temps (et donc de coût) de développement au moins. Ceci dit, il faut se prévenir de l’idée consistant à considérer que, parce que la norme existe et décrit un protocole, tout le monde – y compris les néophytes – pourront prendre en charge une conception. Les protocoles sont complexes et une simple lecture même approfondie d’un document outre qu’elle est franchement rébarbative est loin de remplacer l’expérience.

En tout état de cause, il s’agit d’une démarche extrêmement positive qu’il faut encourager. Le risque essentiel est de sélectionner un standard devenant obsolète rapidement, risque limité si un minimum de soin est apporté lors du choix.

Utiliser des composants issus du monde civil : Il s’agit du 2ième aspect. La tâche n’est pas si aisée qu’il y paraît.

Le problème de la gamme de température : Il est nécessaire de prévoir la mise en œuvre de ces composants sur une gamme de température élargie. Accessible pour des composants simples (transistors) ou à structure régulière (mémoires), l’exercice se complique notablement pour des circuits complexes tels que des processeurs. Ces derniers peuvent, par exemple, comporter des structures en partie asynchrones visant à optimiser les performances mais qui ne sont validées par le fournisseur que sur la gamme de température spécifiée. En cas d’utilisation sur une gamme élargie, il y a alors des risques de conflits internes liés à des temps de propagation tangents (courses de chemin). On constate des comportements aléatoires sur une ou plusieurs plage(s) de température plus ou moins réduite(s).

Par ailleurs, l’idée consistant à dire que « nos besoins étant proches de ceux de l’automobile, nous aurons là une source d’approvisionnement nous convenant » pourrait bien de se révéler fausse. En effet, s’il est vrai que les contraintes sont similaires, il est plus que probable que l’industrie automobile va s’orienter vers la conception de SoC, donc de circuits dédiés inaptes à remplir nos fonctionnalités.

Le problème de la pérennité : Les cycles des composants utilisés pour des applications civils sont sans commune mesure avec les besoins des militaires. Il ne s’agit même plus de risques mais d’un élément à considérer de base : Il faudra faire évoluer la définition de tout équipement militaire tout au long de sa durée de vie pour traiter les problèmes d’obsolescence. Le cas le plus simple est lorsqu’il suffit de remplacer un circuit par un autre de fonctionnalité équivalente. Exemple type : les mémoires, pour peu que la carte ait été conçue de manière à pouvoir câbler des circuits de capacité plus importante. L’autre situation extrême, beaucoup plus difficile, est lorsque qu’il n’est plus possible de trouver un composant équivalent. Dans ce cas, il faut au moins prévoir une reprise de la carte et des couches basses du logiciel.

Disponibilité des composants : Certains composants, essentiellement dédiés aux applications Télécom. ou Automobile par exemple, risquent de ne plus exister sous leur forme classique mais uniquement virtuelle.

Information des fournisseurs : Bien entendu, dans tous les cas de figure, les fournisseurs restent plutôt avares en information. Nous serons donc tenu au courant des disparitions de composants de manière parcellaire et quant à obtenir des données détaillées sur ce qu’il est nécessaire de tester et comment pour envisager d’utiliser des circuits sur une gamme de température étendue, là c’est du domaine du rêve. Non seulement, ils n’y ont aucun intérêt financier, mais en plus ils ne voudront sûrement pas s’engager à nous fournir des informations et, en plus, à les tenir à jour en cas d’évolutions.

UNE SOLUTION ALTERNATIVE : LE « SYSTEM ON CHIP »

Devant un tableau, il faut bien le dire, un peu noir, comment pouvons nous réagir. Il y a probablement plusieurs possibilités, mais dans ce papier, nous nous contenterons d’en aborder une : Les « Systems On Chip » ou « SoC ».

Définition

Depuis déjà plusieurs années, les progrès des lithographies sont impressionnants et permettent d’intégrer dans un seul circuit plusieurs millions de portes. Cela a permis de développer des processeurs puissants, mais ceux ci ne représentent finalement « que » le marché des PC et des stations de travail. Il y a bien d’autres applications industrielles ou grand public qui peuvent bénéficier de ces possibilités et sont à l’origine même du concept de System On Chip.

Un SoC est un circuit dédié, intégrant sinon toutes, du moins les principales fonctions d’un calculateur. Elles sont relatives à chaque application, mais on retrouve typiquement :

- 1 ou plusieurs cœur(s) de processeur
- 1 ou plusieurs cœur(s) de DSP (Digital Signal Processing)

- des périphériques :
- ✓ des interfaces bus système (ARINC, MIL-STD-1553…)
  - ✓ des gestionnaires de liaisons séries
  - ✓ des ports parallèles
  - ✓ des timers / horloges temps réel
  - ✓ des contrôleurs de commande moteur (générateurs PWM)
- et bien entendu – ce serait dommage de ne pas en profiter – des blocs de logique dédiée.

La figure 1 propose un synoptique générique d'un SoC. On retrouve finalement des notions proches de celle d'une structure de calculateur classique, avec des blocs fonctionnels connectés à un bus on-chip. Pour ce dernier, il n'est, malgré tout, pas facilement imaginable de reprendre des standards classiques tel que, par exemple un bus PCI. En effet, certaines contraintes liées à la technologie sont à considérer (exemple : éviter d'avoir des potentiels flottants en interne circuit, donc par de lignes 3 états…). Toutefois, des standards apparaissent. Il convient de noter les efforts sur ce sujet d'organismes tel que VSIA (Virtual Chip Interface Alliance).

Il est aussi possible de prévoir des blocs analogiques ainsi que des convertisseurs analogiques / numériques et inversement.

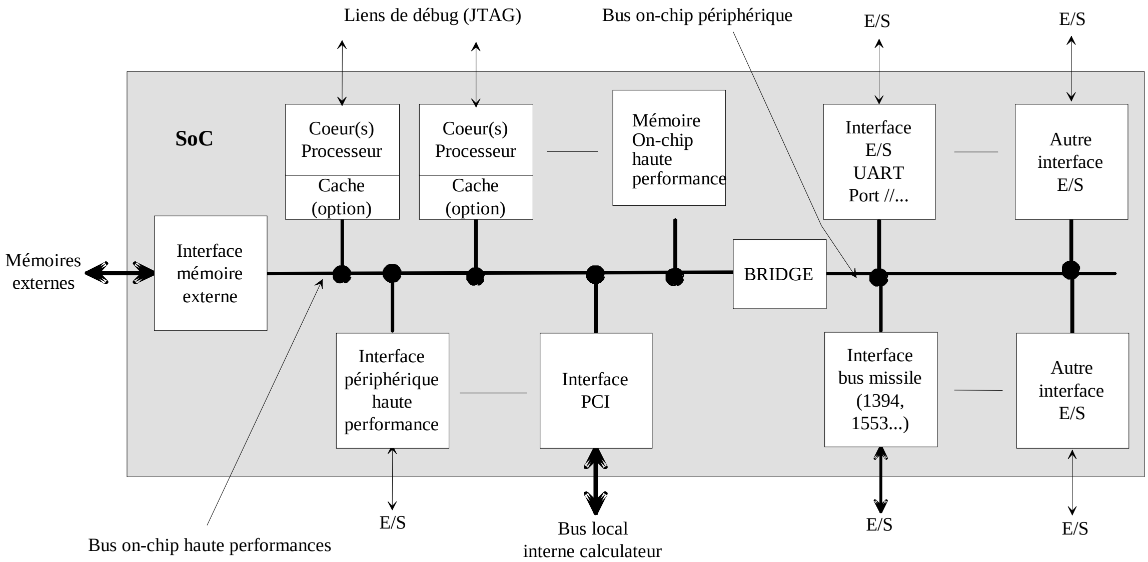

Figure 1 : Synoptique générique d'un SoC

Les marchés

Le principal marché à l'origine de cette tendance est indubitablement celui des télécommunications qui allie à la fois :

- un fort besoin d'intégration pour répondre aux attentes des consommateurs quant au poids et à l'autonomie des téléphones portables
- mais aussi de gros volumes, ce dont se félicitent les fondeurs.

D'autres applications apparaissent, tels que les équipements audio / vidéo et l'automobile.

L'ensemble des marchés cités est caractérisé par de gros volumes en production associés à des coûts très faibles.

Ce qui est aussi certain, c'est qu'on ne voit aucun signe laissant penser à une inversion de tendance. C'est plutôt le contraire, il est probable que l'on verra apparaître de nouveaux débouchés dans les domaines industriels et surtout grand public.

Les grands fournisseurs (d'outils entre autres mais pas exclusivement) l'on bien compris : Il suffit de faire un passage sur les sites web respectifs ou d'assister à quelques conférences pour en être convaincu. Tout tourne autour du SoC, à un point tel qu'il vaut mieux être un peu méfiant vis à vis de ce qui s'en réclame…

Il en est de même au niveau de la presse : Il n'est pas une seule publication qui n'ait pas son lot de références au SoC !

Il ne s'agit donc pas simplement d'un effet de mode, mais d'une tendance bien réelle et durable.

Quelques définitions complémentaires

Avant d 'aller plus loin, il est nécessaire de préciser certaines définitions.

Les circuits dédiés. Par circuits dédiés, on entend ASIC (Application Specific Integrated Circuit) ou FPGA (Field Programmable Gate Array).

Le synoptique ci dessous (figure 2) résume les principales étapes d'un développement type pour ces circuits. Alors qu'il apparaît linéaire, il ne l'est pas dans la réalité. Par exemple, il est certain qu'il y a un

rebouclage entre les phases « Faisabilité », « STB » et « Architecture ». De même, si un problème est découvert durant une phase de vérification, il y a correction, celle ci devant être effectuée généralement dans l'étape précédente ou encore avant. Par exemple, un problème découvert en Vérification « 2 » peut devoir être corrigé en retournant à l'étape de « Modélisation ». Enfin certaines tâches n'ont pas été mentionnées pour ne pas surcharger le synoptique. Elles n'en sont pas moins importantes. Il s'agit de l'insertion de dispositifs de test ou encore du floorplan (ou pré-placement, indispensable pour préparer le routage et éviter des problèmes lors de l'étape de Vérification « 3 »).

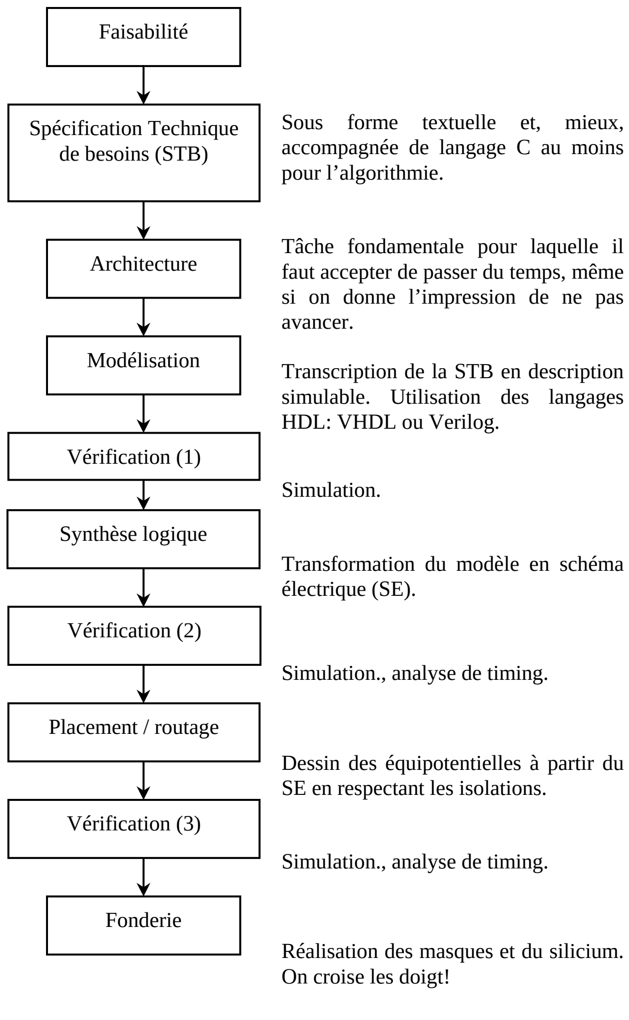

Figure 2 : Flot de conception d'un circuit personnalisé

Les flots ASIC et FPGA restent très voisins, étant entendu qu'il n'y a évidemment pas de fonderie dans le cas des FPGA mais la programmation d'une mémoire.

Précisons que la portée de ce § est bien limitée aux circuits personnalisés, ce qui ne correspond qu'à une phase du développement d'un SoC, dont le flot complet sera traité après

Les IP ou « Intellectual Property ». La notion de SoC est indissociable de celle d'IP (sans pour autant en avoir l'exclusivité). Les IP peuvent être définies comme des composants virtuels. Il s'agit donc de blocs fonctionnels qui peuvent être achetés. Le marché est particulièrement actif et l'offre très fournie. On trouve la plupart des fonctions listées au § « Définition du SoC ». Il est aussi possible de les développer en interne société. Elles correspondent alors à des fonctions très spécifiques à l'activité et que l'on souhaite pouvoir réutiliser dans plusieurs applications.

Il est intéressant de rentrer un peu plus dans le détail, sachant que la maîtrise sur le long terme d'un SoC (ou de n'importe quel circuit mettant en œuvre un IP) est fonction du type d'IP utilisé (ou instancié). On distingue :

- *Les Soft IP* : Les blocs fonctionnels sont décrits en langage HDL et sont accompagnés de testbenches et de directives de synthèse logique. Celle solution permet de maîtriser entièrement le modèle du SoC et assure une bonne pérennité à long terme. Par contre, elle demande un peu plus de travail lors de la phase de développement.
- *Les Firm IP* : Les blocs fonctionnels sont fournis sous forme de schémas électriques. Là encore, des testbenches sont disponibles ainsi qu'un modèle comportemental autorisant les simulations de haut niveau (Vérification « 1 »). Dans ce cas, l'effort de conception est, bien entendu, moindre par rapport au cas précédent. Par contre on ne maîtrise pas du tous les aspects fonctionnels. Cela peut être très pénible durant le développement si le bloc n'est pas correctement développé et validé. De plus, les modifications éventuelles ultérieures du SoC seront plus délicates.
- *Les Hard IP* : Le bloc fonctionnel est, dans ce cas, synthétisé, placé et routé par le fondeur. Pour certains blocs, critiques en terme de performances en vitesse, ce choix est le meilleur. Toutefois, il est clair que l'on est entièrement dépendant de la politique du fournisseur : On n'a aucune maîtrise sur les aspects fonctionnels ni, pire encore, sur la pérennité. Le fondeur peut très bien décider de ne pas porter une Hard IP vers une nouvelle technologie tout en arrêtant celle utilisée. La situation alors délicate à gérer, encore plus s'il s'agit d'un cœur CPU, avec les impacts logiciels associés...

Les conditions d'accès sont très variées, rien de bien stabilisé n'ayant déjà été instauré. En général, il est nécessaire d'acquitter un coût d'accès à la licence, avec en plus des royalties sur les circuits en production. Notons que, dans certains cas, il n'y a pas de royalties et qu'il est aussi possible de disposer d'IP sans droit d'accès à la licence (même pour certains IP considérés comme complexes tel que des cœurs CPU) ! Ceci dit, le budget IP est généralement important, et dépendant d leur type. Les Soft IP sont, bien sûr, les plus chers.

Outre le classement précédent, on distingue généralement 2 grandes catégories :

- *Les « Commodity IP »* : Ce sont les blocs d'usage courant. On retrouve les fonctions PCI, USB, UART… L'offre est très riche.
- *Les « Stars IP »* : On y classe traditionnellement les cœurs de processeur et les fonctions émergentes. Toutefois, force est de constater que l'on assiste, en particulier pour les cœurs de processeur, a des situations un peu abusives. La complexité d'un tel cœur est, approximativement, de 40 000 portes (RISC 32 bits sans opérateurs flottants), ce qui n'est pas énorme. Les coûts (notamment des soft IP), par contre, sont généralement *très* élevés.

Lors de la sélection des IP, il importe de prendre en considération :

- *Les coûts* : Accès licence, royalties mais aussi support / maintenance.
- *La qualité des fournitures*. Il importe de savoir si un minimum de règles de conception des IP a bien été respecté : Conception synchrone, sur fronts montants uniquement, … La facilité de l'instanciation des blocs dans le modèle (et donc coûts et délais associés) en dépend largement. Les publications à ce sujet sont nombreuses, on citera, par exemple, l'initiative OpenMore de Mentor / Synopsys.

Actuellement, la tendance pour les « Stars IP » est très orientée vers les Hard IP (pour des raisons de coûts !) et vers les Soft IP pour les autres. Notons toutefois une évolution encore assez récente qui apparaît, celle des « Soft IP configurables ». Il s'agit de générer un bloc suivant les besoins spécifiques (dans une certaine mesure) de l'utilisateur. Ainsi, ARC propose, moyennant le chargement via Internet, d'un programme permettant de créer un cœur de DSP et l'environnement de développement logiciel en fonction d'un certain nombre de choix. Tensilica offre une approche similaire peut être plus aboutie, aussi pour un cœur processeur : Les besoins utilisateurs sont décrits via Internet et la Soft IP est générée par Tensilica et transférée, toujours via le net. Cette voie permet des options de configuration plus complexes. Nul doute que cette voie a de l'avenir, ainsi qu'Internet comme média de communication et d'échange.

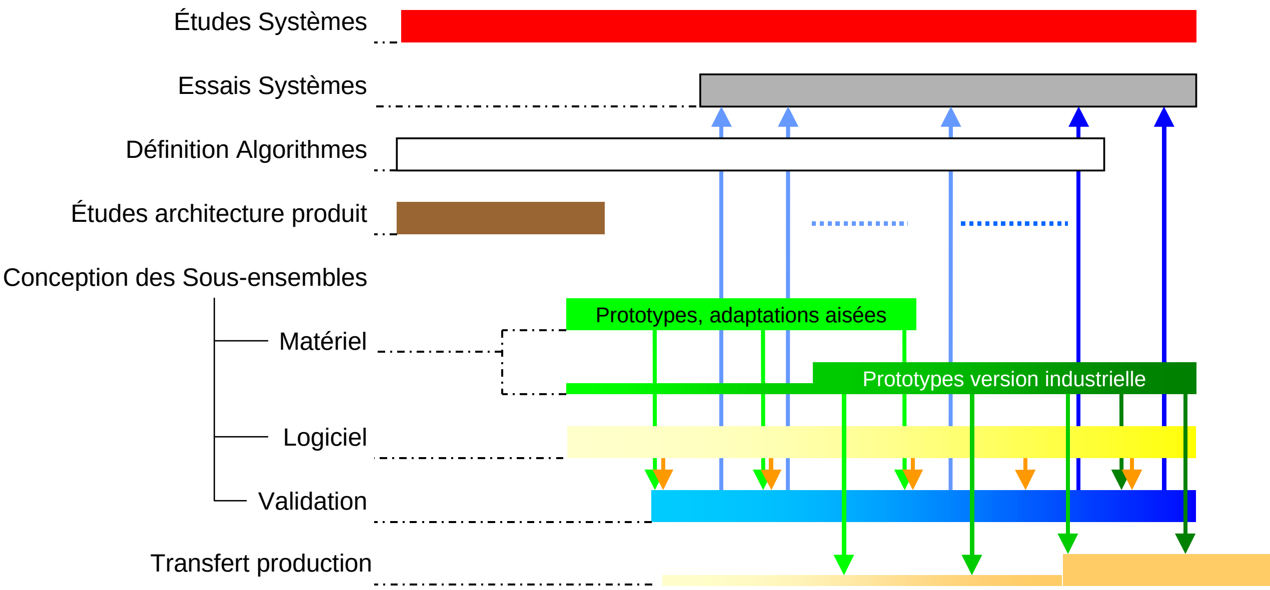

Figure 3 : Flot de développement d'un SoC

FLOT DE DEVELOPPEMENT D'UN SOC

Là encore, nombre de publications existent sur le sujet. Une chose est sûre, il n'y a pas de flot standard, applicable quel que soit le type d'activité de la société. Dans ce §, on va donc s'attacher à préciser les grandes étapes à prévoir avec les différentes options possibles pour chacune d'elles ainsi que quelques écueils à éviter.

On partira pour ce faire du synoptique de la figure 3.

Le flot proposé est basé sur la réalisation d'une maquette à base de FPGA en plus du développement des prototypes en forme mettant en œuvre le SoC. C'est un choix dont l'intérêt est décrit dans un des § suivants.

Implication des équipes Système

Le 1ier point à préciser est qu'il n'est pas imaginable de dissocier les aspects Système / Algorithmique du processus de conception d'un SoC. Si cette démarche est sans doute très présente dans la culture d'entreprises du domaine des Télécommunications, elle l'est beaucoup moins dans des sociétés, par exemple de l'aéronautique. Deux raisons à cela :

- L'historique des Sociétés
- Les différences existant au niveau de la notion de système. Dans le domaine de l'aéronautique, le système met en œuvre un ensemble d'équipements complexes, pas nécessairement basés sur les mêmes technologies (mécaniques, optiques…).

Les responsables du Système et de la définition des algorithmes doivent être très impliqués dans les études d'architecture. Il est nécessaire d'optimiser les algorithmes et de les orienter en vue d'en faciliter l'implémentation. Cette démarche était classique, voire naturelle au tout début de l'électronique essentiellement à cause des limitations de cette technologie naissante. Elle s'est - à tord - largement affaiblie avec la généralisation des structures programmables. Il paraît sain de la remettre au goût du jour non pas du fait de limitations technologiques mais plutôt de coûts en production.

Par ailleurs, en cas d'erreur découverte une fois le SoC réalisé, toute modification risque d'être longue et coûteuse si une solution logiciel n'est pas applicable. Fort heureusement, on commence à voir apparaître des outils permettant la fourniture de Spécifications Techniques de Besoins (STB) simulables donc d'une part validées par rapport aux besoins et d'autre part pouvant servir de modèle de référence pour la conception du SoC. Il convient enfin de noter qu'il est beaucoup plus difficile de valider par simulation des évènements asynchrones que synchrones. Même si ce n'est pas toujours possible, on cherchera à les éviter.

Le plan de développement

Le 2ième point important est de définir en début d'affaire le plan de développement et de préciser entre autres :

- S'il est nécessaire de passer par une phase maquette.
- Les différentes étapes de validation et les entrées nécessaires à celles ci.
- Le planning, bien entendu, avec le calage du début du développement du prototype en forme.

Passage par une phase maquette

Il est fortement souhaitable pour :

- Pouvoir mettre au plus vite à disposition des équipes Système des versions intermédiaires de calculateur.
- Envisager l'intégration matériel / logiciel avant de pouvoir disposer du prototype en forme.

Besoin des équipes Système. Disposer au plus vite de calculateurs permet aux équipes Système de commencer progressivement les intégrations. Il est clair qu'au début de celles-ci, il n'est pas nécessaire de pouvoir activer toutes les fonctionnalités prévues pour le calculateur. La gestion des E/S sera donc initialement proposée et complétée progressivement en fonction des souhaits émis au niveau Système.

Cette démarche est aussi une aide pour les concepteurs du calculateur. Même si les simulations permettent d'aller très loin dans la validation, on ne peut simuler que ce dont on a les modèles. Ce n'est pas nécessairement le cas de tous les éléments connectés au calculateur. Dans ce cas, on écrit un modèle, mais qui, souvent simplifié, ne représente pas toujours le comportement réel. Les essais avec les équipements réels sont de bon tests.

Intégration Logiciel. L'autre intérêt majeur de disposer d'une maquette est de pouvoir commencer l'intégration Logiciel avant d'avoir le prototype en forme. A ce sujet, on voit apparaître une multitude d'émulateurs ou d'accélérateurs Matériel dont on retrouvera l'intérêt au niveau des simulations après synthèse. Ce genre de moyen peut être utilisé pour faciliter l'intégration logiciel lorsque l'on cherche à effectuer celle ci en utilisant le modèle HDL du SoC. Complété avec des environnements de co-simulation (tel que Seamless de Mentor ou Eagle-i de Synopsys…), il est possible, pour les équipes logiciel et de développement du SoC de travailler chacune dans leur environnement. De plus, en simulation, tous les nœuds internes du circuit sont accessibles, ce qui facilite grandement le débuggage. Enfin, au niveau du SoC, le logiciel applicatif constitue un testbench rêvé. Malheureusement, il convient de rester réaliste : La puissance des machines, même associées à un accélérateur, reste en deçà des besoins nécessaires à la simulation d'un logiciel applicatif complet. On limitera donc cette approche au niveau des handlers de base du logiciel.

La mise en œuvre d'accélérateurs n'est pas évidente. Ils représentent un investissement conséquent et reposent soit sur des structures propriétaires soit, c'est de plus en plus souvent le cas, sur des FPGA. Dans ce cas, bien souvent, il faut aussi disposer de la chaîne de développement FPGA. Il sera nécessaire de considérer, pour le développement, la tâche de partitionnement vers plusieurs FPGA avec aussi les étapes de placement / routage de chacun d'eux. C'est assez lourd… et redondant avec la maquette. Enfin dernier inconvénient relatif à ce genre d'investissement : La pérennité est limitée ! En effet, ces moyens reposent sur des technologies très évolutives (FPGA), donc rapidement obsolètes.

Les étapes de validation

Le synoptique de le figure 3 le montre, les étapes de validation sont nombreuses et menées à bien par des équipes différentes. Par ailleurs, on s'en doute bien, elles sont fondamentales, d'où l'intérêt de les préparer soigneusement. Il est donc largement souhaitable d'établir un plan de validation le plus tôt possible après le plan de développement et décrivant chaque étape de validation avec les entrées / sorties, qui fournit quoi et qui fait quoi. Cela présente les avantages :

- de s'assurer que rien n'aura été oublié (validation de certains modes fonctionnels)

- de ne pas non plus valider 2 fois la même chose, ce qui peut coûter cher en temps
- de fiabiliser le planning de développement, en précisant les responsabilités.

Ce plan de validation doit être tenu à jour et enrichit en permanence.

On se limitera, dans ce §, aux validations fonctionnelles. Les techniques de validation sont essentiellement basées sur des simulations, associées à des essais effectués avec les maquettes et prototypes.

Les simulations. Plus les simulations sont faites à haut niveau, plus elles sont rapides. On a donc tout intérêt à envisager de commencer au niveau Système, en créant des Spécifications Techniques de Besoins simulables. Les validations de haut niveau peuvent ainsi être faites directement par l'équipe système ce qui est plus efficace.

Au niveau des modèles développés pour les besoins de la phase Maquettage, la priorité est d'en disposer rapidement. Les simulations sont donc réduites (ce qui ne veut pas dire supprimées), mais complétées par des essais sur table.

Le SoC, quant à lui, doit être validé de manière intensive et à toutes les étapes de conception. Il convient de noter que les simulations fonctionnelles sont longues.

Au niveau du modèle HDL, le temps passé est essentiellement dû à la définition des thèmes de test et à la création des testbenches correspondants. De plus, il est souvent difficile de savoir si la validation est exhaustive ou non. C'est particulièrement vrai pour des applications de traitement d'images. Par contre, les temps machine restent acceptables.
Par ailleurs, il faudra bien comparer les résultats de simulation par rapport à une référence et ce de manière automatique. On voit bien, là encore, l'intérêt de disposer d'une Spécification Technique de Besoins simulable.
Pour revenir à la définition des thèmes de test, il est important d'y associer, bien sûr les concepteurs du SoC, mais aussi les utilisateurs :

- au niveau système, y compris les responsables de la définition des algorithmes, et ce pour éviter toute incompréhension
- au niveau carte, de manière à fiabiliser la définition des interfaces avec le reste des circuits des cartes.
- au niveau logiciel, c'est aussi à ce niveau que l'utilisation des handlers logiciel de base constitue un excellent testbench, ainsi que cela a déjà été précisé.

Après synthèse et placement / routage, les temps des simulations fonctionnelles sont fondamentalement prohibitifs. Pour assurer la cohérence des tests, elles ont pour base les testbenches définis au niveau de la validation du modèle HDL. Mais, du fait de la forte complexité de ces circuits, les temps machine sont importants, pouvant durer plusieurs semaines (sur plusieurs stations de travail). On limite donc ce type de simulation au strict minimum et on s'attache plutôt à utiliser un outil d'analyse statique de timing. Celui ci est, de toute façon indispensable à une validation correcte au niveau structurel (après synthèse). Eventuellement, des outils de preuve formelle peuvent constituer aussi une aide mais ils ne marchent généralement pas très bien pour des structures algorithmiques complexes, du moins actuellement.

Essais sur table. Ce type d'essai est très classique. On notera tout de même :

- l'intérêt qu'il y a de bien les formaliser de manière à éventuellement les transformer en testbench
- en cas de problème, l'importance qu'il y a de fiabiliser la cohérence des prises en compte des corrections au niveau des maquettes (FPGA) mais aussi au niveau du SoC

Enfin, même sur maquette, en cas de problème, il est souvent plus facile d'en trouver l'origine en simulation où l'on a accès à l'ensemble de nœud du circuit, plutôt que sur la réalisation matérielle.

La gestion des plannings

On l'a vu, une bonne gestion des étapes critiques permet logiquement de fiabiliser le planning de développement. L'autre aspect à maîtriser est la relation avec les intervenants extérieurs.

Sous-traitance de conception : Elle n'est, bien sûr, pas obligatoire. Dans le cas où on y a recourt, en particulier pour la conception de blocs fonctionnels en HDL, il est souhaitable d'imposer des règles de conception qui permettent de s'assurer de la qualité de conception et d'un interfaçage aisé avec le reste du circuit

Là encore, les recommandations définies dans le cadre de l'initiative OpenMore sont une excellente base.

Il est aussi largement préférable que le sous-traitant utilise les mêmes outils de conception que ceux mis en œuvre dans la société.

Placement / routage, relations avec le fondeur : Il s'agit d'un cas un peu particulier de sous-traitance. C'est souvent le fondeur qui se charge du placement / routage étape souvent assez délicate et qui, en cas de problème peut durer fort longtemps. Deux règles essentielles sont à respecter :

- Même si l'on cherche à être indépendant des technologies, il est souhaitable de sélectionner le fondeur au plus tôt, et de mettre en place des échanges sur l'avancement du projet et les règles de conception qu'il peut vouloir imposer.
- Avant d'envoyer un circuit pour le placement / routage, on aura tout intérêt à passer par une étape de pré-placement, et de prendre en

compte le routage de(s) horloge(s). Cela évite nombre d'allers / retours, souvent pénibles et longs.

Plannings trop optimisés : Bien sûr, le développement doit être le plus court possible. Il ne faut tout de même pas tomber dans le piège consistant à « oublier » des tâches. En particulier, il ne faut pas considérer que, parce qu'on utilise des IP, il n'y a aucun effort de conception à prévoir. Il y a généralement une logique d'interfaçage à concevoir. Un bon exemple est celui du couplage d'un cœur CPU sur un bus on-chip. Il serait bien surprenant que les 2 blocs aient été conçus en même temps, sans évolution aucune de l'un par rapport à l'autre.

Recouvrement des activités de conception FPGA (maquette) / SoC : A condition de bien le prévoir au niveau de l'architecture des circuits, il est imaginable de reprendre des blocs HDL développé pour la maquette pour le SoC proprement dit et inversement. Par contre, il faudra faire attention à la cohérence des fichiers, en particulier, suite à la prise en compte des évolutions.

Intégration Matériel / Logiciel et Système

Ce thème a déjà été abordé pour justifier l'intérêt de la phase Maquette. Toutefois, à un moment donné, il faudra bien intégrer le prototype en forme avec le SoC… et bien sûr, il y aura des problèmes !

Au niveau logiciel, les techniques de débuggage n'ont aucune raison d'être différentes de celles utilisés avec des structures programmables classiques.

Au niveau système, il est certain qu'il faut prévoir des dispositifs intégrés dans le SoC et permettant – au minimum – de connaître les données échangées entre blocs.

Enfin, rappelons l'intérêt qu'il y a à disposer d'un modèle et permettant un débuggage souvent facilité, moyennant la définition d'un test précis.

TECHNOLOGIE ET PERENNITE

Avantages / inconvénients de l'approches SoC

Les avantages de l'approche décrite se retrouve à divers niveaux :

Les aspects thermiques, la consommation : L'intégration silicium permet souvent de diminuer la puissance dissipée. Si la consommation n'est généralement pas un problème pour des applications aéronautiques, les aspects thermiques eux le sont. Le choix d'une technologie ASIC (avec fonderie) par rapport à une filière FPGA est, à ce sujet préférable.

Les coûts en production : Les structures de ce type sont beaucoup plus simples, mettant en œuvre moins de cartes et moins de composants. Autant de facteurs réducteurs de coût en production. La consommation diminuant, on gagne aussi sur la complexité des blocs alimentation.

Les dispositifs de drainage des calories se simplifient.

La fiabilité : La maîtrise de la consommation et la réduction du nombre de composants permettent d'améliorer la fiabilité des calculateurs.

Les inconvénients : Bien sûr, il y en a toujours :

Accès fonderie : Dans le cas du développement d'un SoC basé sur une technologie ASIC (par opposition à FPGA). La lithographie à utiliser sera du 0.25 ou 0.18 µm. Les coûts de réalisation des masques sont importants. De plus, les fondeurs, surtout actuellement, recherchent de gros volumes ce qui n'est absolument pas notre cas au niveau des applications aéronautiques. Il convient de remarquer, pour ces 2 aspects que ce débat sur l'accès aux fonderies date du début de la technologie ASIC. Jusqu'à maintenant, nous avons toujours trouvé des fondeurs acceptant de travailler avec nous. Par ailleurs, des techniques d'accès multi-projects wafer et multi level mask se développent, limitant l'envolé du prix des masques.

Conditions d'achat : C'est bien connu : Les sociétés ont horreur d'acheter de grosses quantités couvrant les besoins de plusieurs années. C'est malgré tout ce qu'il faut se préparer à faire ! En effet, pour un SoC développé en technologie ASIC, on demandera au fondeur de lancer un batch de wafers, ce qui représentera sans doute si ce n'est toute, au moins une bonne partie de la série ! Ceci dit, ce problème est aussi de plus en plus souvent rencontré dans le cadre de l'utilisation de composants civils, et donc de FPGA.

Risques et coûts de développement : Dés que l'on parle ASIC, on voit souvent les cheveux de dresser sur la tête de nos interlocuteurs ! A tord ! Finalement, le coût de développement d'une fonction en ASIC est similaire à celui d'une structure programmable aux coûts de fonderie prêts. Même si ces derniers sont élevés, ils ne sont malgré tout pas rédhibitoires par rapport aux coûts de développement d'un calculateur. Par ailleurs, les outils et les méthodologies utilisés permettent de largement fiabiliser le développement et de donc de réduire les risques.

Souplesse : Bien sûr, une fois la phase de fonderie terminée, il est sinon difficile en tout cas long et coûteux de modifier une fonction pour prendre en compte une évolution. Il est important d'insister là sur l'étape d'architecture de manière à rendre la structure paramétrable (exemple : pouvoir modifier les paramètres d'un filtre par programmation). De plus, on l'a vu, le SoC intègre beaucoup de blocs standards, le tout contrôlé par logiciel du fait de l'intégration d'un cœur CPU (ou plusieurs). L'idée de circuits ASIC rigides n'est donc plus vraiment de mise et, en tout cas ne l'a jamais été pour les technologies FPGA. Enfin, le côté positif est que « Réfléchir avant d'agir » permet souvent d'éviter des erreurs et de gagner en temps de développement...

SoC : Le choix FPGA / ASIC

Même si la décision est prise de s'orienter vers du FPGA, il est souhaitable de conserver la possibilité de migrer vers de l'ASIC et donc d'appliquer les règles idoines. On commence à voir apparaître des FPGA intégrant des cœurs de processeur : Attention à la compatibilité avec une possible filière ASIC.

Le FPGA est, bien entendu, plus souple en développement en cas d'évolution mais est notablement plus cher en production. Il faut donc faire un bilan économique en fonction des quantités à produire.

Le FPGA présente aussi le risque d'obsolescence. Alors que les mémoires SRAM étaient le véhicule technologique utilisé par les fondeurs pour mettre au point les nouvelles lithographies, elles ont été remplacées par les FPGA qui ont aussi une structure régulière et pour lesquels on assiste à l'envolé des complexités. Ces composants sont donc à la pointe des technologies, mais cette course risque de laisser rapidement de côté les versions à peine plus anciennes. Il y aura, bien sûr, des FPGA permettant de remplir la fonction, mais la compatibilité avec la carte n'est pas assurée.

Au moment du choix, il convient d'être prudent par rapport à la réalité des complexités annoncées par les fournisseurs de FPGA. 1 million de portes FPGA est loin d'être équivalent à 1 million de partes ASIC ! En plus le rapport est variable en fonction des fournisseurs et même des familles. Idem pour les vitesses qui correspondent souvent à des « best case », c'est à dire la fréquence maximum avec des fan out de 1… ce qui est rarement le cas dans la réalité !

La pérennité

Ce thème est la trame de ce document en entier, avec, toutefois, quelques aspects complémentaires.

Propriété du circuit : La société est propriétaire de son design et du modèle HDL. Moyennant le respect de quelques règles, le portage d'une technologie vers une autre n'est pas un problème majeur.

Une limitation existe en cas d'utilisation de Firm ou Hard IP, pour lesquelles il faudra se limiter à de grands standards du marché.

A noter, que, à ce niveau, il ne s'agit pas de dire que la technologie (lithographie) ne deviendra pas obsolète. Par contre le fait de pouvoir migrer vers une autre, même si les coûts ne sont pas nuls, permet d'éviter la reprise de cartes et pire encore du logiciel.

Conditions d'achat : Celles là même évoquées précédemment et présentées comme un inconvénient ! Le fait de faire du stock en quantité suffisante pour la série met à l'abrie de tout surcoût du fait de problèmes d'obsolescence…

Gamme de température de fonctionnement : A partir du moment où la société contrôle l'ensemble du développement, il est parfaitement possible de valider le SoC (les timings) sur une gamme de température correspondant à nos besoins. En production, si le fondeur refuse d'effectuer les tests en température, il est encore possible de réaliser ou de faire réaliser des tests spécifiques puisque l'on est aussi propriétaire des vecteurs de test.

CONCLUSION

L'approche SoC nécessite d'adapter certaines méthodes de développement au niveau validation par exemple et d'effectuer un contrôle rigoureux du développement. Par contre, elle est particulièrement attractive sur les plans des performances au sens large mais aussi de la pérennité.

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Integrated Modular Avionics with COTS directed to Open Systems and Obsolescence Management

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1. SUMMARY

This paper describes how to design open computer systems for mission critical applications within the avionics of military aircraft using "Commercial Off The Shelf" (COTS) computer components[1]. Design aspects of "Integrated Modula Avionics" (IMA) are incorporated. How these aspects contribute to an effective obsolescence management is also described. The content of this paper is presented within the context of projects currently running at the European Aeronautic Defence and Space (EADS) Deutschland GmbH, Military Aircraft Business Unit (MABU), which are dealing with the subjects COTS and obsolescence.

First the primary design aspects of open computer systems will be discussed as well as internationally recognised associations and standards dealing with this topic. The potential behind the use of open computer systems for future avionics of military aircraft is to be unveiled.

It will be described, how to set up open computer systems, considering IMA conform design aspects, which fulfil the requirements directed to the equipment of mission critical avionics in military aircraft. Within this context the core aspects of IMA will be introduced and compared to conventional systems.

Regarding design aspects for open computer systems the design principals developed by the Allied Standard Avionics Architecture Council (ASAAC) have to be mentioned. Firms of the three participating countries - England, France and Germany – are co-operating to set up a European accepted standard for avionics HW and SW designed for use in military aircraft.

The use of COTS computer HW and SW will be presented as a cost effective solution for setting up open computer-systems for use in aircraft, until ASAAC conform HW and SW solutions are available. Possible COTS based configurations will be discussed referring to a current COTS computer system. This system is ruggedised for flight and built up with COTS HW and run by a COTS real time operating system. Successful flight-testing of the system has taken place.

Due to the rapid developing IT technology, today's computer systems quickly face obsolescence. Avionics for military aircraft are especially vulnerable because of the long development cycles. The opportunities of managing obsolescence, given by the use of COTS computer HW and SW, are identified with respect to future avionics of military aircraft. Affected qualification and flight-clearance aspects as well as the porting of avionics SW-applications, originally developed for proprietary computer systems, onto COTS computer systems will be mentioned.

2. OPEN SYSTEM ARCHITECTURES

The majority of computing systems in service in military aircraft of today, show a proprietary system architecture[2]. They are designed as Line Replaceable Units (LRUs) developed for special functions or cover a cluster of functions. Fitted together in the avionics of the EF2000, LRUs can be found for example as DASS computer, as navigation computer, as digital symbol generator etc. (Figure 1). Mostly HW and OS of these LRUs are invariant. Therefore modifications, as well as enhancements and technical innovations, that become necessary during the life cycle of a LRU, maybe can't be carried out. Any cross use of proprietary computer systems for different, mission-critical avionics functions may not be practicable due to their specific system design. Each function is implemented on a specially developed computer system, integrated as LRU in the aircraft avionics.

Today avionics systems of military aircraft, based on LRUs designed for special functions, represent a symbiosis of multiple LRUs. Thereby the high complexity of avionics systems, due to their comprehensive functionality, is further driven by the specific properties of the different LRUs - proprietary external HW interfaces, data-protocols etc.. Development, production, integration testing, logistics, maintenance and upgrading of today's avionics systems are therefore comprehensive and cost intensive over the whole lifecycle.

2.1 Main Design-Aspects

Pushed by the described deficits of current LRUs, open system architectures are required for future avionics of military aircraft. The core aspect of open systems is a flexible system design based on well established HW and

[1] Thereby processor-boards, I/O-boards, chassis, operating systems etc. are referred to, which are available fully developed at the commercial market.

[2] Today's avionics computer already follow a modulare HW and SW design. However modules and components are coupled via supplier specific HW and SW interfaces.

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SW interfaces. By using open systems it is expected [1] to overcome the deficits of current LRUs:

- Avionics equipment following flexible HW and SW concepts shall support the use of state of the art technology.
- An open architecture can shorten equipment development and secure the upgrade potential needed.
- The scope of possible HW and SW solutions will grow.
- A well established upgrade potential and enhanced resource procurement shall help to reduce the pressing obsolescence risks encountered with current avionics equipment.
- Development, procurement and lifecycle costs can be significantly reduced.
- The integration of components into an equipment as well as the integration of equipment into an existing network, like the avionics of a military aircraft, shall be eased.
- The previously described scope of open system architectures is established via HW and SW offered in the commercial market.

Applied to computer systems for the avionics of military aircraft this implies the following focal aspects for an open system design [2] to be considered during the definition phase of a computer system:

- A modular system design with mechanical and electronic autonomous components[3], similar to that of modern LRUs, has to be followed.
- The integration of such components into a functioning system has to follow clearly defined, fully developed, commercially supported and therefore stable HW and SW interfaces. This refers to both external and internal HW and SW interfaces.
- HW and SW interfaces chosen for open system architectures have to be available to a broad clientele of users and should be continuously maintained and further developed by internationally recognised standardisation institutions.
- HW and SW interfaces suited for open computer systems have to support modifications and upgrades of existing and future avionics applications.
- The HW configuration of open computer systems must feature quick and easy maintenance and upgrade possibilities, e.g. well established interfaces, which guarantee the exchangeability of inoperative or obsolete components, boards and parts against state-of-the-art solutions. Within chassis spare slots must be available for the insertion of additional boards.

2.2 International Efforts

Efforts to establish open systems in military equipment find their origin in the USA. They were initiated by William Perry, 1994 Secretary of Defense and a strong advocate of an intensive usage of commercially established standards, specifications and state-of-the-art technology.

The same year Dr. Kaminski, Under Secretary of Defense for Acquisition & Technology, strengthened this direction when announcing, that new acquisitions of electronic equipment have to follow an open system architecture. To support this process he founded the Open Systems Joint Task Force (OS-JTF) and established it as an institution.

Due to this announcement of the Department of Defense (DoD) concerning military command, control, communications, computer and intelligence (C4I) systems, documents were set up, which describe definition, specification and development guidelines for open systems as well as the related HW and SW interfaces. Leading documents related to this topic are [3]:

- Joint Technical Architecture (JTA) framework
- Joint Aeronautical Commanders Group (JACG) guide specifications
- Generic Open Architecture (GOA) framework
- Technical Reference Codes (TRCs)
- Technical Architecture Framework for Information Management (TAFIM), cancelled in January 2000 and replaced by the current, equivalent JTA standards.

By the Institute of Electrical and Electronic Engineers (IEEE) open systems are defined via two basic standards:

- P1003.0/D15 Open Specification[4]
- P1003.0/D16 Open System Environment

These standards are accompanied by further IEEE standards.

2.3 Potential for Realisation

Open systems are principally suited for all kinds of avionics systems in military aircraft. Due to the strong adherence of open architectures to well established interfaces, avionics computer systems are especially suited for first introduction. HW and SW computer components have experienced a broad entry in many different industries. An intensive competition between the different suppliers of computer components has led to standardised HW and SW interfaces, which were quickly and widely accepted, e.g.:

- VME, PCI or cPCI are well established data-bus interfaces for coupling different computer components
- ATR is a standard for chassis, ruggedised for flight
- As standard format for the geometry of computer boards Eurocard is used
- POSIX is established as SW standard for application and user interfaces

Regarding this selection of standards already helps to fit together HW and SW components according to the principals of open system architectures, summarised by

[3] Such components are designed as Embedded Systems, e.g. as SBC, combining dedicated equipment functions.

[4] "Public specifications that are maintained by an open, public consensus process to accommodate new technologies over time and that are consistent with international standards", Open Specification Definition IEEE P1003.0/D15..

the OS-JTF [1] in the Electronics Reference Model (Figure 2). A central design aspect of this model is a layered HW and SW architecture. The single layers of this model can communicate with each other via the SW and HW interfaces listed above. A computer system, based on the layered architecture of the Electronics Reference Model, is open for the exchange of single HW and SW computer components. This helps to reduce obsolescence risks associated with computer systems.

Computer HW and OSs, which satisfy the standards listed above and classified as ruggedised for flight, can be bought on the commercial market. Future aircraft programs as well as facing upgrades of aircraft in service may use existing COTS computer HW and SW to design open computer systems for use in military aircraft. Existing and newly developed avionics SW applications have then to be aligned to a layered architecture, described by the referred Electronics Reference Model.

A first approach will have to be restricted to mission critical computer systems to reduce the risk always associated with the introduction of new technologies.

3. KORRELATION WITH INTEGRATED MODULAR AVIONICS (IMA)

Design principals of open systems conform with the basic principals of Integrated Modular Avionics, although IMA goes much further.

Regarding the actual needs of aircraft operators IMA [4] propagates modular architectures for avionics systems. Intentions of IMA are:

- Improved maintenance of Avionics systems. Adaptations and enhancements during the lifecycle of avionics systems have to be simplified .
- To introduce a refined fault tolerance and fault management for avionics systems concerning detection, isolation and correction of in flight faults.
- To take advantage of shorter technology development cycles for avionics.

Applied to the HW of avionics computers IMA conform configurations will consist of components coupled via few dedicated HW and SW interfaces. These interfaces comply with international established standards. Within such computer systems, components can easily be exchanged and replaced by further or completely new developed components. Due to that, obsolescence risks are reduced. A further central design aspect derived from IMA is to build up component clusters within cabinets[5], which serve as data management centres. Step by step this development direction of avionics computers has then to be applied to further avionics systems. Therefore, in the future the design of military avionics will no longer be determined by multiple, separate computer systems or LRUs, coupled via data-busses and point-to-point connections. Consequently the diversity of electronic components in today's chassis respectively LRUs will be reduced. Instead common modules, components which are available in a few variants only, will handle different avionics functions. These common modules will be mounted in a small number of cabinets, connected via high speed data-busses, operating with a high bandwidth. In case of an in flight HW or SW failure, an in flight reconfiguration of the avionics system enables avionics functions to be maintained, depending on the severity of the failure that has occurred and the necessity of a function for save aircraft operation. Thereby a greater redundancy of avionics functions is reached with less components compared to the number of components needed for redundancy purposes in today's avionics systems.

Associated with avionics SW, IMA follows a strict subdivision. It distinguishes between SW applications for pure avionics functions, the OS and the driver SW for operating the HW components of an equipment. These three autonomous SW components are related via highly standardised SW interfaces and together make up the SW of an avionics equipment.

Avionics equipment following IMA design aspects shows a modular system architecture, based on few variants of common HW and SW components, which can be used for different avionics applications. The subdivision of the SW of an avionics equipment as well as the communication between the equipment's HW components via well established, highly standardised interfaces, e.g. VME, cPCI etc., lead to an equipment architecture, classified by SW and HW layers. These layers are again coupled via well established, highly standardised interfaces and make up the technical layout of modern IMA avionics equipment. Such a layered architecture corresponds with the Electronics Reference Model mentioned in Chapter 2.3 as an architecture for open systems. Therefore this model can be referred to as a development step for current avionics towards IMA.

Looking beyond the establishment of open systems, ASAAC is producing a set of IMA implementation standards. ASAAC is run by aerospace and IT companies in a tri national alliance between the participating countries England, France an Germany.

4. IMPLEMENTION GUIDELINES FOR OPEN SYSTEM ARCHITECTURES

Currently two different implementation concepts correlating with each other, ASAAC and COTS, are followed by EADS Deutschland GmbH to introduce open systems in military aircraft avionics. Both concepts follow different priorities and time scales. ASAAC is directed to the long-term and focused on a completely IMA reliant avionics in military aircraft. Until ASAAC conform HW and SW components are available, future configurations of avionics computer can make use of COTS. The focus of this concept is short-term, propagating a cost saving introduction of open systems in avionics, thereby contributing to the mitigation of the obsolescence risks related with current avionics systems.

[5] Contrary to chassis in service today, cabinets are part of the aircraft structure and represent mounting areas for a number of processor boards, I/O boards etc..

4.1 ASAAC

ASAAC is working towards the establishment and demonstration of standards for defining the architecture of modular avionics for military aircraft within the next four years. First ASAAC related HW and SW components shall be available on the commercial market in 2005. In a next step the ASAAC standards, agreed by the three European partner nations, shall become NATO standard (STANAG). Focal point of all ASAAC efforts towards modular avionics for military aircraft is a layered HW and SW architecture (Figure 3). Within ASAAC, the Electronics Reference Model, referred to in chapter 2.3 as layered architecture model for open system designs, is experiencing a refinement. The Application Layer (AL) is the upper layer of the ASAAC architecture model, containing all SW applications dealing with pure avionics functions as well as application dependent SW modules for data management and communication. Beneath the AL the Operating System Layer (OSL) is placed, comprising the operating system and general SW modules for system management and communication purposes. Within the ASAAC architecture model the Module Support Layer (MSL) is the lowest SW layer, closest to the HW. It is a cluster of HW related driver SW needed for operating the respective HW. AL, OSL and MSL are coupled via standardised interfaces - Application to Operating System Interface (APOS) and Module to Operating System Interface (MOS) - according to the ASAAC layered architecture model. APOS and MOS are defined with in the ASAAC standards.

System architectures, designed in layers according to the ASAAC model, imply a semi-automatic configuration of the HW and SW of an avionics system by system tables, so-called blueprints. In these Blueprints no unique HW and SW configuration is described but a variety of configurations, which cover possible in flight failures of single HW or SW components. After an in flight failure has occurred, an in flight reconfiguration[6] of the remaining HW and SW components maybe necessary. A semiautomatic writing of blueprints is supported by SW tools. Thereby system engineers are supported to develop different configurations for the HW and SW components of an avionics system with an affordable amount of effort. These configurations have to cover the failure free system status as well as possible failures of HW and SW components of an avionics system. During operation of an avionics system, the blueprints are loaded as data files in the HW components of an avionics system.

ASAAC therefore not only defines standards for the design of open system architectures for military aircraft avionics but also investigates SW tools for the realisation and implementation of ASAAC standards respectively IMA.

[6] After an in flight failure occurred, a reconfiguration becomes necessary, if avionics functions needed for aircraft operation are no longer available via the remaining HW and SW resources. If latter are not sufficient to offer all avionics functions of a fully operable avionics system, then avionics functions no longer needed for aircraft operation have to be shut down. The SW of avionics functions needed, then has to be newly distributed onto the remaining HW by a reconfiguration of the avionics system.

Until ASAAC conform HW and SW components are available, components offered on the COTS market are an adequate solution. Then already the next generation of computer systems for military aircraft can follow an open system design. Simultaneously, as discussed in chapter 5, obsolescence risks related with such computer systems are reduced.

4.2 COTS

EADS MABU has designed a Universal Aircraft Computer (UAC) based on COTS components as a short-term available computer system for mission critical military aircraft avionics, which has an open system architecture. The UAC is gaining increasing recognition for upgrade programs of in service military aircraft, the design of an avionics system for a new trainer aircraft and as an answer to the obsolescence problems encountered with current avionics of military aircraft. Further more severe cost restrictions and a shrinking procurement market for military ruggedised computer systems [5] are additional drivers for a lasting use of COTS components.

4.2.1 Central Design-Aspects of COTS Computer-Systems

The UAC is designed as a multiprocessor system for mission critical avionics applications. To fulfil this requirement, the basic version of the UAC design comprises a conduction cooled VME backplane fitted 1 ATR chassis, in which the following VME boards[7] are integrated:

- three PPC603e processor boards, two of them enhanced with MILbus1553B PCI mezzanine cards (PMC)
- one analog input board
- one graphic board

With the UAC a group of external electronic interfaces can be served:

- RS232
- Ethernet
- Discretes
- Analog Input
- RGB
- MILbus1553B
- ARINC429
- ATM
- Fibre Channel

These interfaces enable the UAC to be integrate into the avionics of military aircraft.

For operating the UAC, the commercially available realtime operating system LynxOS is used. Driver SW fitting with the chosen HW components is made available by the HW supplier for different operating systems. The operating system has to be configured according to the HW used. Since the operating system is fitted with a POSIX interface, UNIX compatible SW applications are supported on the UAC.

[7] To be integrated into the conduction cooled ATR chassis of the UAC, boards have to be fitted with wedge-locks compliant with IEEE 1101.2 for mechanical fixing.

The HW components used for the UAC have been specified by the supplier as ruggedised according to MIL-STD, concerning physicals loads the system will experience when operated in military aircraft. Therefore the HW can resist extreme temperature fluctuations, moisture, vibration, shock, EMC etc.. Supplier delivered CoCs grant, that the components are qualified for the relevant physical loads. Dependent on the CoCs is the licensing of the UAC for use in military aircraft.

The basic configuration of the UAC described above is only one possible configuration of the UAC. However the system architecture of the UAC is fixed, which means the UAC is a commercial VME based computer system housed in an ATR chassis. This chassis then is configured for a particular application by use of ruggedised Double-Eurocard[8] VME boards. Further the chosen chassis has to have spare slots, in case the integration of additional VME boards becomes necessary later on due to enhanced functional requirements. External interfaces of the UAC are selected according to the avionics system the UAC is planned to be integrated with. HW, OS and SW-drivers are procured via the COTS market. Although all HW components of the basic configuration of the UAC are offered by one supplier, a close coupling towards a single supplier has not taken place.

Like with proprietary computer systems, each intended UAC configuration has to be defined via requirements and a specification. Derivatives of already existing UAC configurations may then be described via amendments to existing documents. Therefore time savings related with the use of COTS components are mainly seen within the development phase of a computer system. If fully developed COTS components are deployed for the configuration of computer systems, a development phase as used for proprietary solutions will no longer be applicable. However, the definition and procurement phase can be barely shortened by the use of COTS. Nevertheless, the total time needed to configure a COTS computer system will be less than that needed for a proprietary solution. This implies cost savings parallel to the lower procurement costs of COTS components. How far LCC savings are possible with COTS solutions is part of an ongoing investigation.

4.2.2 Context to Open Systems

The UAC is built up from commercially available HW, OS and driver SW, coupled via well established HW and SW interfaces and follows a layered system architecture like that stated for open systems and ASAAC.

With VME as data-bus for inter-board communication and PCI as local data-bus for adding mezzanine cards to VME-boards, well established and therefore technical stable electronic interfaces have been chosen for the architecture of the UAC. The stability of these interface technologies becomes obvious regarding the broad variety of VME boards and PCI mezzanine cards offered by many COTS suppliers. American National Standards Institute (ANSI), IEEE and VMEbus International Trade Organisation (VITA), are all well known organisations for technical standardisation matters, that have maintained the VME- and PCI- standards. These interfaces, the geometry of the chassis and the mechanical board fixing guarantee the exchangeability of UAC components in the long-term. Enhancements of the UAC are supported by free VME slots on the VME backplane together with free PCI slots on integrated VME boards.

Know-how as well as experience concerning interfaces, HW, OS and driver SW of the UAC are absolutely necessary when using COTS components. Only then is it possible to take advantage of the modification and extension potential inherent to the open architecture of the UAC. Plug-and-Play features are commonly not supported by COTS components. This mainly depends on how strict COTS suppliers adhere to established interface standards in the design of their components. This is also a factor determining if COTS-components from different suppliers can be mixed, although they are classified as VME boards or PCI mezzanine cards.

The open aspect of the UAC architecture has been verified by using it in different projects with requirements that could not be fulfilled with the basic UAC configuration (Figure 4). Therefore the PPC603e board, which within the basic configuration is not fitted with a MILbus 1553B PCI mezzanine card, was replaced by a PPC750 processor board. Additionally a further PPC750 board was integrated into the ATR chassis. Furthermore a mass memory board was added to the configuration and the graphics board was removed. Only boards ruggedised for flight and delivered by the same supplier as the basic version of the UAC were used for these modifications. Within a another modification all three PPC603e boards are replaced by PPC750 boards provided by a different supplier. Since primarily designed for operation in an industrial environment, these boards additionally can be ruggedised for flight by the supplier, if this is a customer requirement. Two of these three PPC750 boards will be fitted with the MILbus mezzanine cards delivered by the supplier of the UAC basic version.

5. OBSOLESCENCE MANAGEMENT

Continuously shorter development cycles within the IT industry accelerates the obsolescence of IT products, with their life cycles getting shorter. Simultaneously this process is accompanied by shrinking government budgets for military expenses. Therefor an effective obsolescence management concerning the avionics of military aircraft is gaining lasting importance. Concerning avionics computers, different kinds of obsolescence risks have to be faced:

- Already when production of a proprietary avionics computer starts, some electronics parts needed may no longer be available, because they have become obsolete since the development phase of the computer has been completed.

[8] The geometric dimensions of double Eurocard boards are: 233.35 [mm] width * 160 [mm] height.

- The performance of aged proprietary computers may no longer be sufficient to serve the enhanced needs of today's avionics systems. Since the underlying technology of these systems has not been further developed, a system upgrade isn't possible.
- Components or parts necessary to repair inoperable computer systems have become obsolete and are no longer available via the respective market and spare stocks built up by the system operator have been used up.

Therefore in recent years international committees and industry have discussed possibilities for an effective obsolescence management regarding the avionics of military aircraft. Open computer systems based on COTS offer several approaches for an effective obsolescence management of military aircraft avionics, as discussed in the following chapters.

5.1 COTS Base

Computer components offered on the COTS market usually are available in the short-term. Therefore the mentioned obsolescence risk due to elapsed time between development phase and production start is not encountered with COTS. Obsolescence risks corresponding with an ageing computer system are mitigated by the common adherence of COTS components to commercially well established HW and SW interface standards. Because of competition COTS suppliers are strongly interested, that their components are compatible with such standards. To stay in business with traditional customers and to gain new customers, suppliers depend on the compatibility of their components with the products of other suppliers as well as the upward and downward compatibility of their own components.

5.2 Layered Model

SW applications, developed according to the layered ASAAC model, can be ported onto different HW configurations with a minimum amount of effort. Using the ASAAC standards allows for later enhancements and modifications of the SW application to be easy performed. Therefore a layered SW architecture, as propagated in the context of open systems, helps to reduce costs, time and effort caused by HW and SW obsolescence, thereby supporting an effective obsolescence management.

5.3 Running Upgrades

Computer systems, which experience short and regular upgrade cycles, will show only little obsolescence between two successive upgrades. As a result, upgrades as well as interim maintenance and repair efforts will be less complex and less costly. However if upgrades are widely spaced, a lasting obsolescence of computer systems is allowed. This will rise complexity and costs for upgrades, maintenance and repair. In the long-term, running upgrades will limit the obsolescence of computer systems, therefore being more affordable than widely spaced upgrades. Again the layered HW and SW architecture of open systems supports an effective obsolescence management when based on running upgrades.

5.4 Design of Avionics Systems by System Tables

A SW tool, which allows a semiautomatic system configuration by writing system Blueprint tables as introduced in chapter 4.1 ASAAC, can also be used for a more effective obsolescence management. However, obsolescence risks inherent to computer systems will not be mitigated. A respective SW tool simplifies the integration of HW and SW modifications, which have become necessary due to the obsolescence of a computer system. Developed for a better and easier design of complex avionics systems, such a tool also serves an effective obsolescence management.

5.5 Life Time Buy

If a COTS supplier intends to stop support and production of a certain computer component, which has become obsolete, he will probably offer his customers a Life Time Buy opportunity for this component [6]. Therefore computer systems based on COTS components enable a refinement of traditional obsolescence management strategies mainly relying on stock building. A customer will no longer be forced to determine and to buy the necessary amount of spares, to cover the whole life time of a computer system, which has just been put into service. He can determine the amount of spares needed for maintenance and repair when offered a Life Time Buy opportunity by the supplier, and thereby avoids a costly capital investment in stocks. Furthermore the inherent uncertainty about the amount of spares needed will have diminished at that time. This alternative is adequate for an effective obsolescence management, especially if it becomes obvious, that a COTS computer system despite his open architecture will experience no more upgrades till the end of his service life.

6. RESUME

COTS computer components, due to their alignment to commercially established international HW and SW interface standards, contain a lasting potential to introduce open computer systems into the avionics of military aircraft. At the same time these computer systems will be cheaper and better in performance then proprietary solutions. Generally even open COTS based computer systems will not fit Plug-and-Play design features. For the configuration of open computer systems based on COTS components comprehensive know-how is necessary about the HW and SW used, as well as about the porting of application SW on different HW platforms. Open, COTS based computer systems for the avionics of military aircraft are an effective approach towards IMA until ASAAC conform avionics equipment is available. The scope for an effective obsolescence management is already determined in the design phase of a system. Open COTS computer systems can help to make this scope given by current technology as big as possible. Finally however the actual market request for such systems will determine the success of this design approach.

7. ABBREVIATIONS

AL	Application Layer
ANSI	American National Standards Institute
API	Application Program Interface
APOS	Application to Operating System Interface
ASAAC	Allied Standard Avionics Architecture Council
ATR	Air Transport Rack
C4I	Command, Control, Communications, Computers and Intelligence
CoC	Certificate of Conformance
COTS	Commercial Off The Shelf
cPCI	Compact PCI
DASS	Defensive Aid Subsystem
DoD	Department of Defense
EMC	Electromagnetic Compatibility
GOA	Generic Open Architecture
HW	Hardware
IEEE	Institute of Electrical and Electronic Engineers
IMA	Integrated Modular Avionics
I/O	Input / Output
IT	Information Technology
JTA	Joint Technical Architecture
LCC	Life Cycle Costs
LRU	Line Replaceable Unit
MABU	Military Aircraft Business Unit
MOS	Module to Operating System Interface
MSL	Module Support Layer
OEM	Original Equipment Manufacturer
OS	Operating System
OS-JTF	Open Systems Joint Task Force
OSL	Operating System Layer
PCI	Peripheral Component Interconnect
PMC	PCI Mezzanine Card
POSIX	Portable Operating System Interface
PPC	Power Processor
SBC	Single Board Computer
STANAG	(NATO) Standardisation Agreements
SW	Software
TAFIM	Technical Architecture Framework for Information Management
UAC	Universal Aircraft Computer
VITA	VMEbus International Trade Organisation
VME	Versatile Module Europe

8. LITERATURE

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[3] United States Special Operations Command, Open Systems Development Plan, August 1996

[4] B. Balser, M. Förster, J.-P. Munk, Anwendung der Integrierten Modularen Avionik in militärischen Upgrade-Programmen, July 1999.

[5] Carbonell, J., Ostgaard, Impact of COTS on Military Avionics Architectures, AGARD CP-581/29, October 1996.

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9. FIGURES

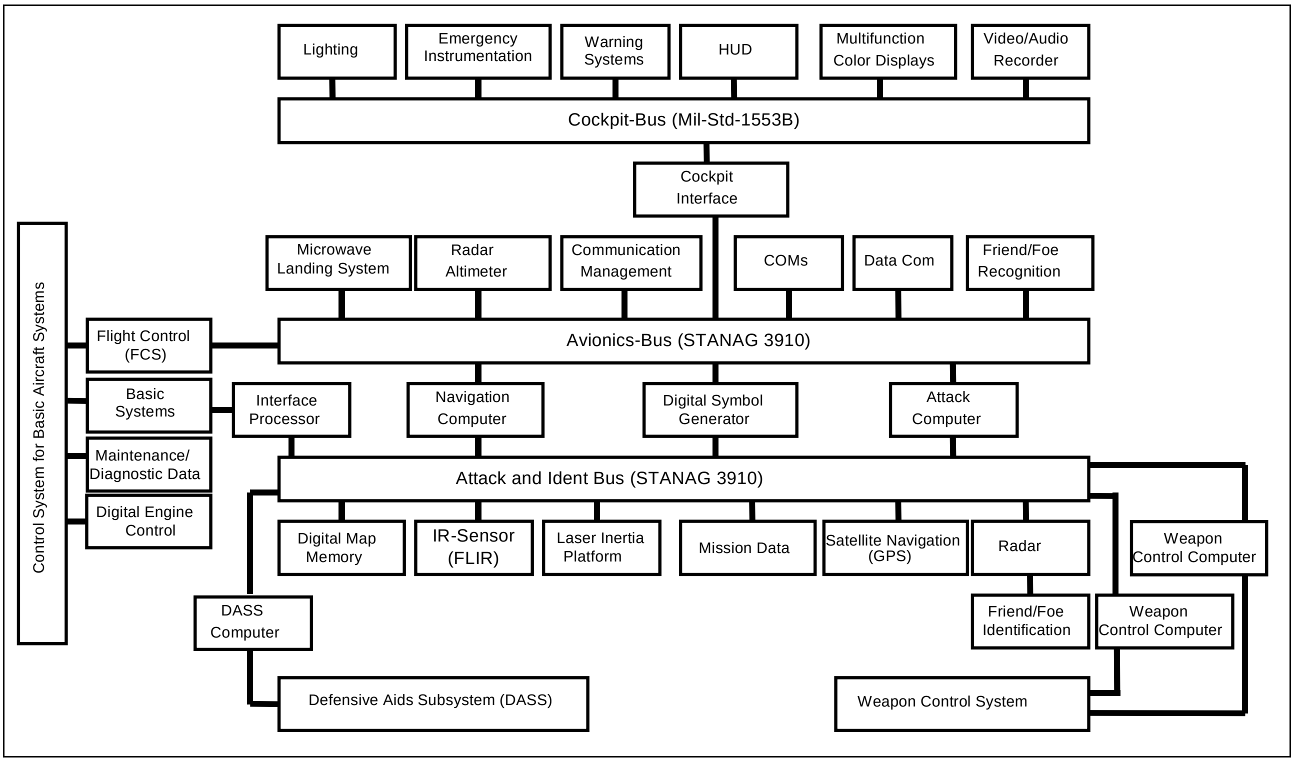
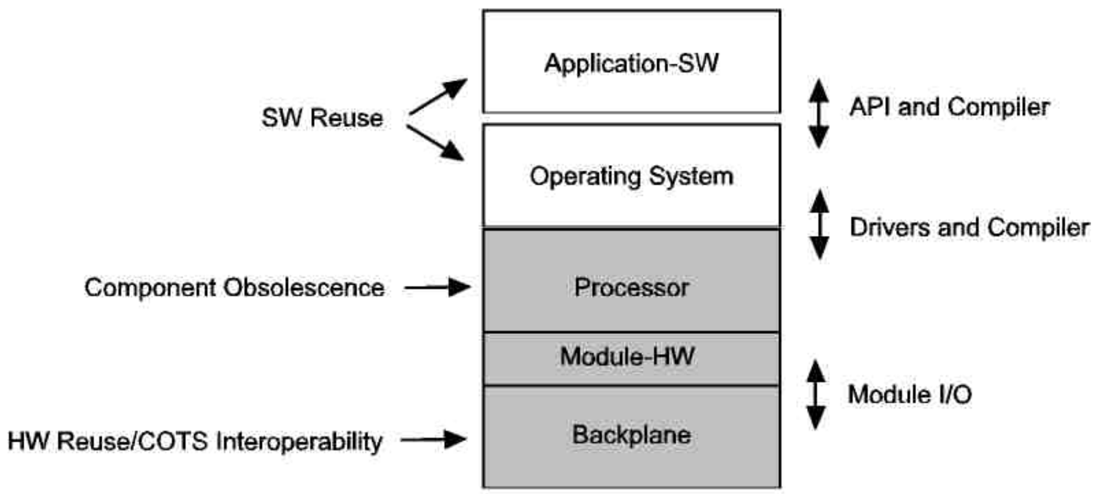


Figure 1: Avionics system EF2000



Identified open system interfaces:	
Language	ADA and C++
Application Program Interface	POSIX
Operating System	UNIX
Data Bus	VMEbus
Local Area Network	Ethernet

Figure 2: OS-JTF Electronics Reference Model

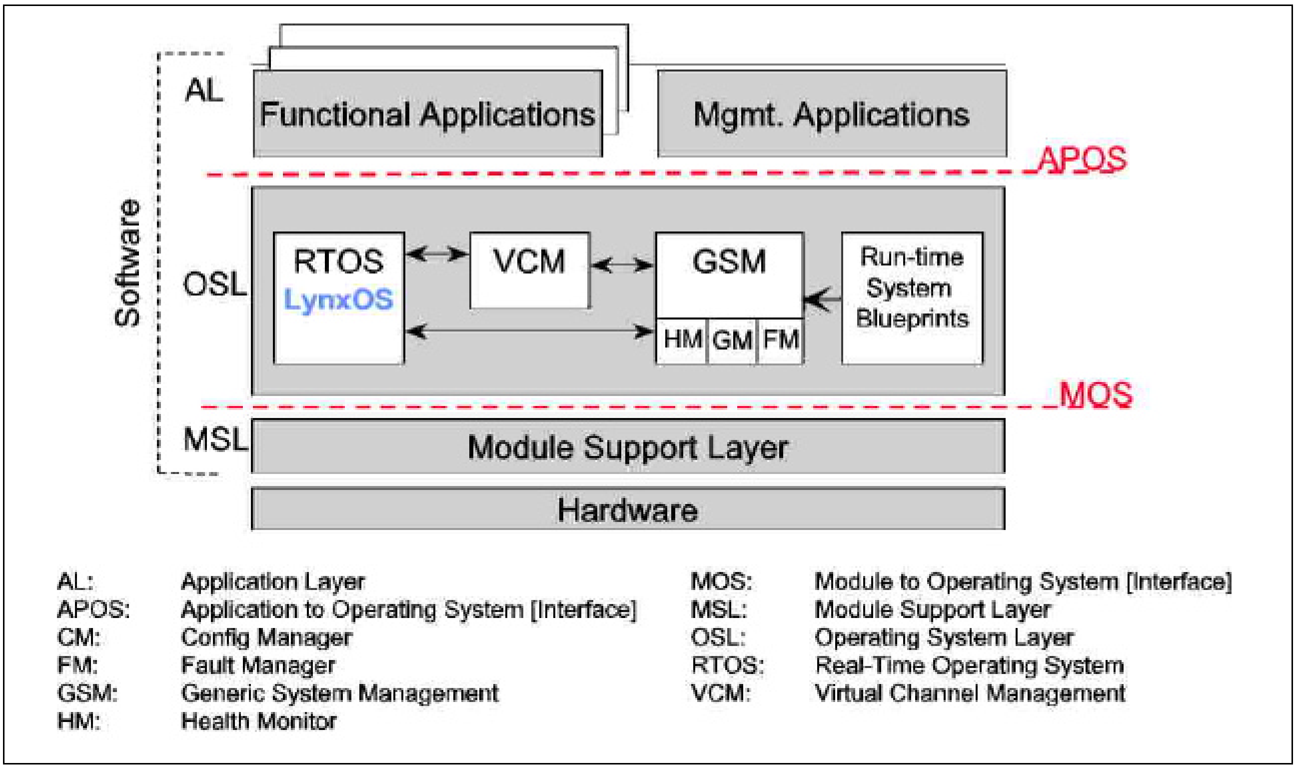


Figure 3: ASAAC model for layered system architectures

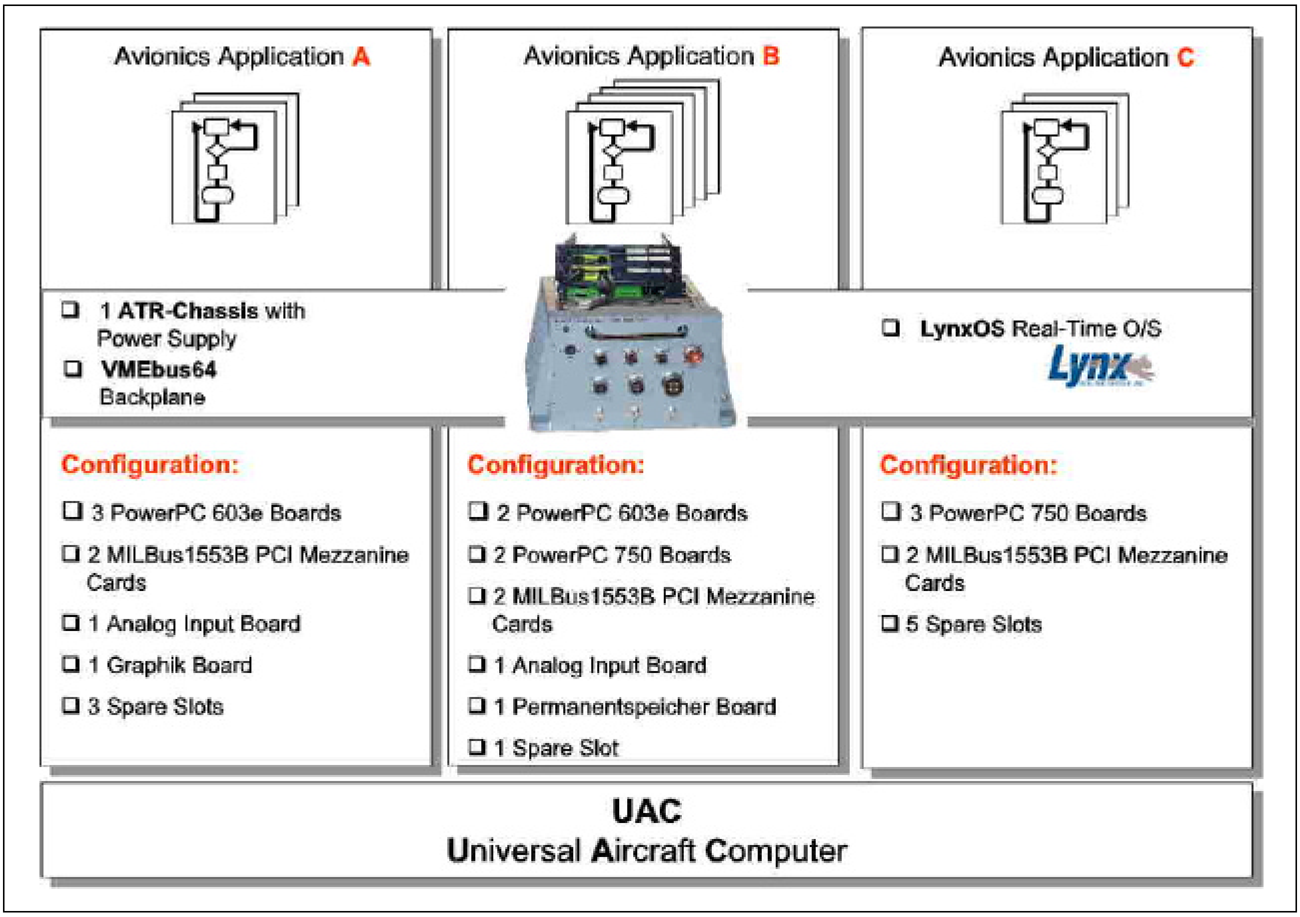


Figure 4: COTS Computer with an open system architecture

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MB-339CD Aircraft Development
COTS Integration in a Modern Avionics Architecture

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1. INTRODUCTION

Obsolescence of electromechanical instruments and navigation sensors is one of the main reasons for new avionics development in military training aircraft upgrade programs.
The growing requirements for advanced trainers in the role of lead-in-fighter aircraft push the development of integrated avionics system where cockpit displays, mission computer, solid-state navigation sensors, communication transceivers and flight data recorders are extensively employed.

The use of COTS (Commercial Of The Shelf) solutions allows to mitigate components obsolescence and to meet the new operational requirements at an affordable cost with reasonable development risk.

The purpose of this paper is to provide an overview of how these concepts have been applied in the development of an innovative, modular and reliable avionics system.

The latest version of the proven MB-339 twin seat jet powered advanced trainer employs a modern state-of-the-art avionics architecture based on standard bus interface (i.e., MIL-STD-1553 and ARINC 429), capable to easily integrate COTS equipment.
The system exhibits a full glass cockpit with three identical and interchangeable Multifunction Displays, Head-up Display and independent get-home instrumentation for back-up flight data presentation: all the cockpit displays use COTS active matrix full colour high resolution LCD's.

COTS solutions are applied at hardware level in computer processing, interface and memory devices, providing state-of-the-art high performance digital technology solutions.
Radio navigation equipment, air data computer and an embedded inertial-GPS platform are employed as proven, off-the-shelf and fully qualified military equipment.

The paper highlights the advantages gained by the employment of COTS solutions in a modern, flexible and expandable avionics architecture. In the paper, the equipment is deliberately described in general terms, omitting any manufacturer reference.

2. MB-339CD AVIONICS

2.1 General

The Aermacchi MB-339CD aircraft (Fig. 1) is a single engine, tandem seat jet trainer designed for advanced and lead-in-fighter training in order to allow pilot's conversion to the latest generation of operational aircraft.

Figure 1. MB-339CD Aircraft.

The aircraft was designed, developed and tested in the middle of the 90's and is currently in service with the Italian Air Force. The first flight was performed on April 1996 while the Final Operational Capability (FOC) was reached on October 1998; an improved version of the aircraft, with additional capabilities, will be delivered on December 2001.

The MB-339CD aircraft design is based on the proven airframe structure, engine and general systems (i.e., fuel, hydraulic, electrical, flight controls and landing gear) fully qualified on the MB-339A model, while a new avionics system is fitted in order to enable training with modern operational techniques, including use of an Head-up Display (HUD), Hands On Throttle and Stick (HOTAS), and Multifunction Displays (MFD's), enhancing mission effectiveness and aircraft survivability (Fig. 2).

Paper presented at the RTO SCI Symposium on "Strategies to Mitigate Obsolescence in Defense Systems Using Commercial Components", held in Budapest, Hungary, 23-25 October 2000, and published in RTO MP-072.

Thanks to the avionics updating, the MB-339CD fills the gap between traditional trainers and new combat aircraft.
The MB-339CD avionics is based on a modern architecture using digital data buses as mean of on-board information exchange between sensors, computers and cockpit displays.

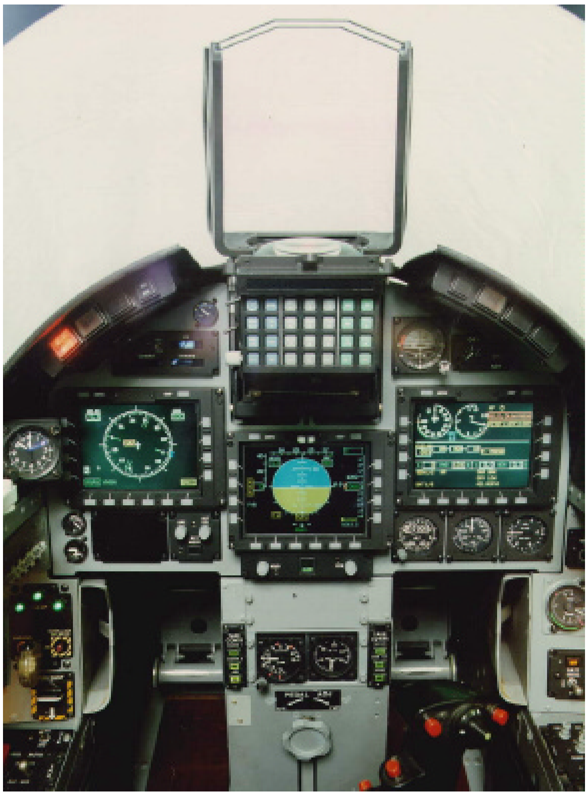

Fig. 2. MB-339CD Cockpit Layout.

The installed navigation sensors, processing equipment and electronic displays not only exhibit high performances in terms of accuracy, growth potential and man-machine interface, but also show improved reliability reducing in service maintenance costs.

This section provides a description of the aircraft sensors, computers, controls and displays, merged in a fully integrated Navigation/Attack system.

2.2 Avionics Architecture

The main components of the MB-339CD avionics are the following:

Sensors

- Embedded GPS-Inertial (EGI) platform
- Air Data Computer with associated Pitot/Static ports and Total Temperature Sensor (TTS)
- Angle of Attack and Angle of Sideslip transducers
- Radio Navigation systems including VOR/ILS, TACAN and ADF
- Radar Altimeter

Computers

- Mission Processor (MP)
- Data Transfer System with embedded Digital Map Generator (DMG)
- Engine Instrument and Crew Alerting System (EICAS) Data Acquisition Box (EDAB)
- Stores Management System (SMS)

Recorders

- Flight Data Recorder (FDR) with Crash Survivable Memory Unit (CSMU)
- Video Cassette Recorder (VCR)

Controls and Displays

- Head-up Displays (HUD) with embedded Data Entry Panel (DEP)
- Multifunction Displays (MFD)
- HOTAS controls
- Heading/Course and Baro/Altitude rotary controls

These components are interconnected, directly or through adequate interfaces, by a MIL-STD-1553 dual redundant data bus called Avionics Bus (Fig. 3).
The Avionics Bus is mainly controlled by the Mission Processor which acts as the primary Bus Controller; in the event of a critical Mission Processor failure, the EGI system is able to provide back-up bus controller capability assuring complete redundancy.

Several equipment such as EDAB, MP, FDR include analog, discrete, video and digital interfaces in order to allow the acquisition of the parameters provided by aircraft devices (general systems transducers, HOTAS and rotary controls) and to allow the integration of equipment which have non-1553 interface.

The system architecture is characterised by a distributed processing capability which allows a rationale and simple allocation of the system functions: the EGI and ADC provide the navigation parameters directly used by the primary flight displays, the EDAB is based on two fully redundant and independent electronic circuits capable to provide in digital form the parameters acquired by the general systems and the MFD include 1553 interface and graphic processing, to autonomously generate the symbology based on the information available on the Avionics Bus.

With these important characteristics the required system redundancy is obtained without duplication of the central processing and symbology generation. The overall result is a simple and reliable architecture.

The high level of flexibility of the avionics system, coupled with the considerable computing capability of the installed computers, allows for a remarkable growth potential such as: self-protection systems (including a

Radar Warning Receiver, a Chaff and Flares Dispenser and a pod mounted active ECM), a Forward Looking IR (FLIR) system, a pod mounted Reconnaissance (RECCE) system, a rangless GPS-based Air Combat Manoeuvring Instrumentation (ACMI) system, and embedded sensors (Radar/RWR) simulation capability.

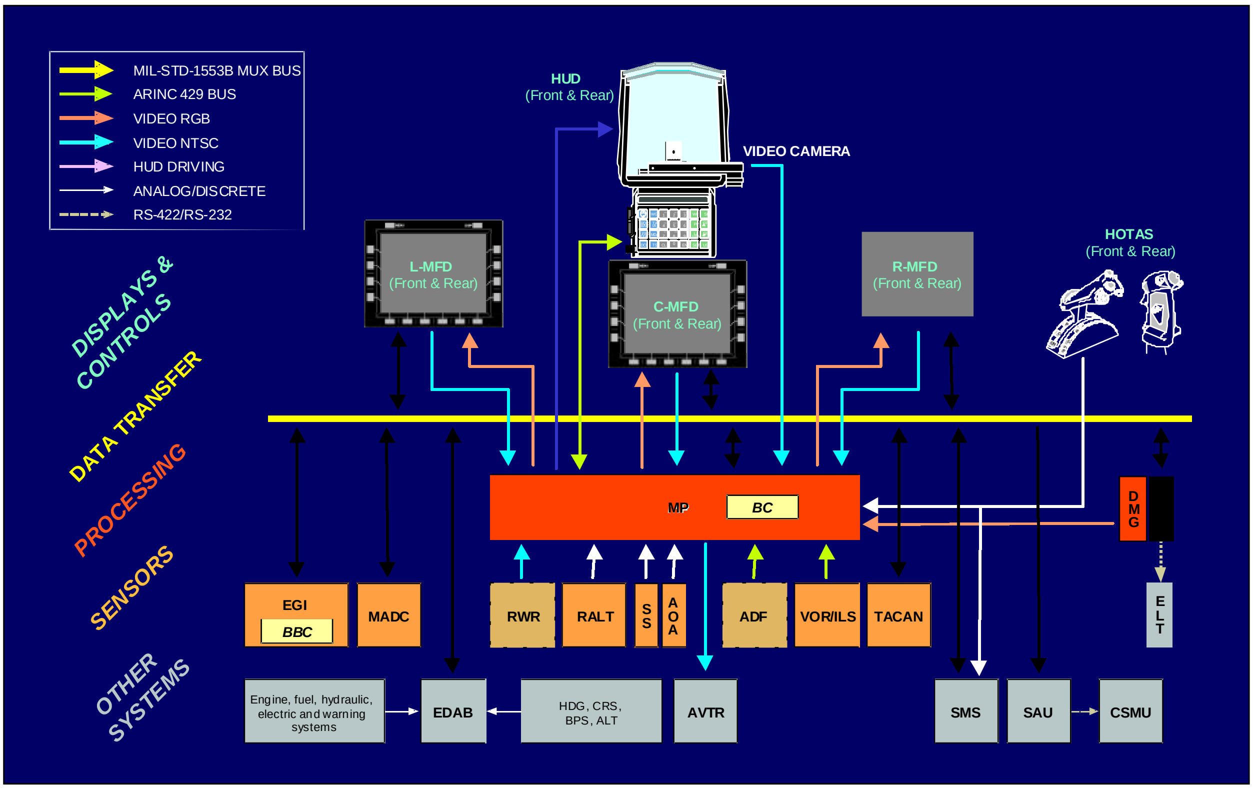

Figure 3. MB-339CD Avionics Architecture.

2.3 Sensors

The **Embedded GPS Inertial** (EGI) platform is a self-contained unit consisting of three Ring Laser Gyros, three solid-state accelerometers and associated electronics capable to guarantee accurate inertial navigation; embedded in the EGI is a tightly coupled GPS receiver module with 6 channels and P(Y) code capability which uses pseudo-range and pseudo-range rate satellite data.

The EGI supplies the navigation/attack system with accurate information related to the aircraft attitude, position, velocities and accelerations: roll and pitch angles, roll, pitch and yaw rates, magnetic and true heading, ground speed, aircraft body axes speeds and accelerations, present position, wind data, steerpoint data, and time data referred to the GPS.

The demonstrated EGI performances are the following:

- Position accuracy (CEP) pure inertial: < 0.8 NM/h;
- Position accuracy (CEP) blended: < 100 m (SPS);
- Velocity accuracy (rms) pure inertial: < 1.0 m/s;
- Velocity accuracy (rms) blended: < 0.03 m/s.

The provided data are always the best available solution obtained by filtering the inertial and GPS data through a Kalman filter. This allows reduction of the Mission Processor workload.

The GPS receiver can work in the Standard Positioning Service or in the Precise Positioning Service mode. Thanks to the GPS integration, the EGI can be commanded to align on ground and in flight with a nominal alignment time of 4 minutes.

The **Air Data Computer** (ADC) with associated Pitot/Static ports and Total Temperature Sensor (TTS) includes extremely accurate pneumatic transducers and, thanks to a powerful computer, is able to provide in digital form the most important air data parameters: total and static pressure, altitude, vertical velocity, baro corrected altitude, indicated and true airspeed, Mach number, maximum allowable airspeed, and outside total temperature.

The ADC guarantees the following performances:

- Pressure Altitude accuracy ± 7 ft (sea level)
- Indicated Airspeed accuracy ± 0.5 kts @ 300 kts
- Temperature accuracy ± 0.5°C

The unit design is characterised by ultra compact and light box (< 0.9 kg) and extremely reduced power requirements (6 W @ 28 Vdc).

The **Angle of Attack** and **Angle of Sideslip** transducers are directly connected to the Mission Processor, which includes the Analog to Digital converter to acquire and convert the parameters.

The **Radio Navigation** system is based on three equipment: VOR/ILS/MB, TACAN and ADF.

The **VOR/ILS/MB** unit is a fully digital VO/LOC, Glideslope (GS) and Marker Beacon receiver, providing both Commercial Standard Digital Bus (CSDB) and ARINC 429 interfaces. The VOR/ILS/MB operates with a frequency control panel and three antennas; it uses digital techniques to read serial input data provided by the frequency control panel, to compute navigation situation and to generate serial data outputs including VOR Bearing, ILS Lateral and Vertical deviations, MB annunciators. The unit design guarantees FM immunity and software verification according to DO-178A, lev. 1.

The **TACAN** receiver-transmitter is a microprocessor-controlled unit operating with two antennas and remote control panel. It outputs bearing, slant range, time to station, range rate and Morse code identification from a standard TACAN ground station. The equipment provides also an air-to-air operational mode for aircraft ranging, bearing and identification reception from equipped aircraft; it includes the complete provision for DME-P function.
The units operates with all 126 X channels and 126 Y channels providing an RF peak power of 750 watts.

The **ADF** (provision) is a microprocessor controlled receiver providing relative bearing between aircraft and the selected ground station. The receiver operates with a frequency control panel and a dedicated antenna. The output data is provided through a digital ARINC-429 data bus.

The **Radar Altimeter** (Radalt) is a solid-state system performing aircraft height measurements with the following characteristics:

- Height accuracy	± 3 ft
- Altitude range	0 to 5000 ft
- Attitude (pitch/roll) range	± 45°

It generates analog signals acquired and processed by the Mission Processor to provide height digital data to be displayed on MFD and HUD; the output data are also used by the MP to provide a low-altitude warning through the Audio Warning Generator.

2.4 Processing Equipment

The **Mission Processor** is the heart of the avionics system since it performs essential functions like Avionics Bus control, Head-up Display symbology generation, HOTAS interface and Navigation/Attack computation.

The equipment is a high performance, 12 slots, full military qualified computer; it is based on a powerful RISC CPU and characterised by a modular design exhibiting the following main features:

- CPU	RISC 3081, 12 MIPS;
- Memory	2 Mbytes RAM, 8 Mbytes FLASH, 128 Kbytes EEPROM;
- Interfaces	MIL 1553, ARINC 429, analog, discrete, video;
- Application Software	ADA language.

The full development phase of the Operational Flight Programme (OFP), including software specifications, coding, verification and validation, has been performed by Aermacchi, assuring a complete in-house management capability of the avionics system.
Under OFP control, the MP is capable to perform the following functions:

- primary 1553 bus controller;
- HUD symbol generation;
- HUD Data Entry Panel interface;
- ARINC 429 interface for VOR/ILS/MB and ADF receivers;
- analog and discrete interface to Radalt, HOTAS, Angle of Attack and Sideslip transducers;
- video interface and switching for HUD Video Camera, MFD's and Video Tape Recorder;
- management of control inputs from MFD's, HOTAS and Data Entry Panel;
- navigation computation including data base management;
- flight director and altitude alerter processing;
- weapon aiming computation.

The **Data Transfer System**, directly connected to the Avionics Bus, allows to update the mission data and to record the flight history data used for mission debriefing purposes. The DTS also includes the Digital Map Generator, which provides raster and vector colour moving map capability.

The equipment consists of a receptacle unit and a removable cartridge, reprogrammable on ground using a Mission Planning and Debriefing Station (MPDS) based on a Personal Computer.
Key feature of the equipment is that the mass memory required by both cartographic files and mission data is fitted in the cartridge, allowing direct access by the map generator and immediate replacement by the pilot.
The unit output is an RGB video signal directly driving the Multifunction Displays through the Mission Processor, while the cartridge uses solid state memory devices with expansible memory capacity: the present configuration is 1 Gbyte Flash covering 1.000.000 km^2 (1:100K) map data.
The in-flight available functions include:

- heading-up or north-up orientation
- scale and zoom selection

- scrolling, freeze and declutter capabilities
- DTED information management including safety height indication
- navigation overlay management
- tactical overlay management

The Engine Instrument and Crew Alerting System (EICAS) Data Acquisition Box (**EDAB**) is the main interface between the aircraft general systems and avionics. It acquires, computes and transmits in digital form all the parameters to be presented on the cockpit displays, relevant to:

- Engine → RPM, Jet Pipe Temperature, Oil Pressure, Fuel Flow
- Fuel → tanks fuel quantity
- Hydraulic → main and emergency pressure
- Electric → generators load
- Anti-ice → heaters status

In addition, the EDAB processes all the information needed to produce visual caution indication displayed on the MFD's and activates the relevant aural messages provided by the Audio Warning Generator.
The equipment is characterised by a fully redundant architecture: two independent sections performs all the above mentioned functions assuring that no single failure leads to the loss of the relevant indication. All electronic circuits and devices, starting from the anolog/discrete input to the 1553 transceiver, are duplicated providing high reliability and fault tolerant operation.

The **Stores Management System** is fully integrated in the avionics system using the MFD as the main pilot interface for display and selection of the stores carried under the wings. In addition a weapon inventory panel is provided to the ground crew in order to enter the armament stores configuration and to check system serviceability. The system includes independent circuits for stores release/launching/firing and emergency jettison operations and, due to the trainer role of the aircraft, its hardware design is optimised to reach the maximum level of operational safety.

The SMS allows the pilot to operate in the following modes:

- Continuously Computed Impact Point;
- Continuously Computed Release Point;
- Lead computed Optical Sight;
- Continuously Computed Impact Line;
- Air-to-Air Missile;
- Dogfight.

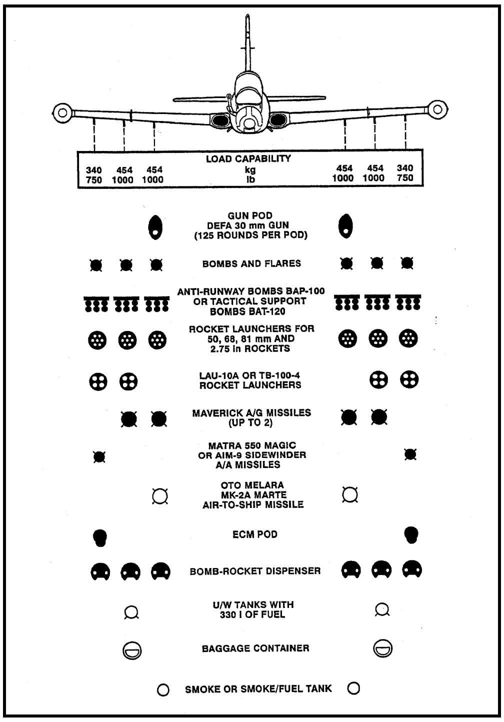

Figure 4. External Loads Capability.

Although light and compact units are installed in the aircraft, the SMS exhibits a wide weapons and external load capability as shown in Fig. 4.

2.5 Recording Equipment

The recording system collects all the information useful for pilot mission debriefing, maintenance trouble shooting and, in case of accident, reconstruction of the last period of flight. The system includes: a Video Recorder, a Flight Data Recorder and an Airborne Strain Counter.

The **Video Tape Recorder** (VTR) records, according to pilot selection, the images displayed on one the front cockpit MFD's or the HUD symbology superimposed on the external world as seen by the HUD Video Camera. In addition to the colour images, the VTR records the communications between the two pilots and between the aircraft and the ground stations.
The VTR uses standard Hi-8mm cassette providing access to commercially available playback units and videocassettes.

The **Flight Data Recorder** (FDR) system includes a Signal Acquisition Unit (SAU) and a Crash Survivable Memory Unit (CSMU), and is used for maintenance and post-accident analysis purposes.
The SAU is capable of receiving a combination of analog, discrete and digital (1153) parameters which are converted, compressed and stored in the embedded memory unit; the same parameters are transmitted to the CSMU where they are stored in a solid-state, non-volatile and protected memory.

The CSMU is designed to withstand stringent mishap conditions including fire temperature, mechanical shock and penetration.
All the data collected by the FDR are stored at lower sample rate in the cartridge of the Data Transfer System allowing immediate data availability for mission debriefing and maintenance.

The **Airborne Strain Counter** allows structural elements monitoring in order to determine the fatigue life of the airframe under real usage.
The microprocessor controlled equipment features the acquisition of seven strain gauges fitted in the most significant points of the aircraft structure and of an accelerometer for data correlation to the aircraft manoeuvres; the processed data are stored in non-volatile matrix memory, downloadable on ground using a PC based ground support equipment for post-processing analysis.

2.6 Cockpit Controls and Displays

The MB-339CD man-machine interface philosophy is based on two identical cockpits (Fig. 2) in order to allow complete monitoring by the rear seat instructor; each cockpit includes an Head-up Display and three identical and interchangeable Multifunction Displays capable to provide all the available formats under pilot's selection. The rear cockpit MFD's can operate in independent or mimic mode to enhance the student monitoring by the instructor. In the event of integrated avionics system failure, a complete set of stand-by instruments is provided in order to guarantee a get-home recovery in safe conditions; it includes: Attitude indicator, Magnetic Compass, Mach-anemometer, Altimeter, Vertical Velocity indicator.

The avionics controls are fitted mainly in the instrument panel for up-front operation: they are based on MFD softkeys and Data Entry Panel keyboard. The HOTAS concept is extensively employed, providing a configuration representative of an actual fighter aircraft.

The **Head-up Display** is composed by a Pilot Display Unit and a Data Entry Panel. The Pilot Display Unit uses dual-flay holographic combiners exhibiting excellent visibility also from the rear seat; it is a raster display whose navigation and attack symbology is generated by the Mission Processor.

The **Multifunction Displays** are “smart” active matrix full colour liquid crystal displays. They are capable to provide the displayed image using both 1553 data words or external video signals: graphic on video capability is also foreseen. The equipment includes 1553 interface, CPU, graphic processor with anti-aliasing capability, video interface and is able to provide as output a video signal of the displayed format for recording.

The MFD main characteristics are the following:

- Display area 5.1 x 3.9 inches
- Display resolution 640 x 480 pixels
- Brightness > 500 CD/m2
- Contrast > 5.5 : 1
- Grey scale 64
- Viewing angle ± 30° horiz., 0 to 30° vert.
- CPU Motorola MC68332
- Memory 1.5 Mbytes FLASH, 1 Mbyte RAM, 64 Kbytes EEPROM

On the bezel of the MFD a group of 16 softkeys are fitted: 2 softkeys on the top allow presentation of the Menu selections and display brightness/contrast control, 6 softkeys on the bottom are used to select the requested format and 8 softkeys on the lateral sides provide pilot's selection according to the displayed format.
Presentation of the requested information is obtained through 12 main formats: the first six show data related to flight condition while the others provide the pilot with system status, check list and special information or procedure. The available main formats are: ADI (Attitude and Directional Indicator), HSI (Horizontal Situation Indicator), MAP, SMS (Stores Management System), SYS (information on general systems), SP (Steerpoint list), IN/GPS (inertial platform alignment and status), STATUS (avionics equipment status), Checklist, MARK, TVC (HUD Video Camera), RWR (Radar Warning Receiver).

The **HOTAS** configuration is derived from F-16 throttle and stick. The rotary controls are located in two separated control panels: the first, fitted below the central MFD, provide the Heading (**HDG**) and Course (**CRS**) set parameters while the second, installed on the right side of the instrument panel, allow the selection of Barometric Pressure set (**BARO**) and Altitude (**ALT**) for altitude alerter function.

All the rotary controls are implemented through incremental Gray encoders providing discrete signals for processing in the EDAB.

3. COTS INTEGRATION

3.1 General

The new avionics system development had the main purpose to provide the basic trainer aircraft with lead-in-fighter improved capability within specific constraints in terms defined development cycle and fixed budget.

The new operational requirements pushed the development of an integrated avionics system, in which sharing of resources and information between subsystems became dominant. This characteristic resulted in improved performance and reliability, whit reduced size, weight, power and costs.
To shorten development cycle and reduce recurring costs, several Commercial-Off-The-Shelf (COTS) solutions were investigated and adopted at three development levels: avionics system design, equipment selection and components employment.

COTS integration in a military application is not an easy task due to the typical military requirements: harsh environments, maximum performance in minimum weight, volume and power envelope, fault tolerance and long term supportability.
Where COTS solutions result unpractical, the reuse of existing military units allows to mitigate the obsolescence problem, while implementation of functions moving from hardware to computer software is extensively applied.

The purpose of this section is to provide a general overview of COTS integration through several examples taken by the MB-339CD avionics system.

3.2 Avionics System Design

In the MB-339CD avionics architecture the transfer of information from sensors to displays and from remote controls to transceivers is completely digital.
An essential feature for COTS integration in the MB-339CD aircraft was the employment of a widely used, non-proprietary standards and protocols (i.e., not forcing to use well defined interfaces for the electronic equipment).
In order to provide high flexibility in equipment selection, several types of standards were adopted:

- MIL-STD-1553B is applicable to the main avionics data bus;

- ARINC-429 is used to interface several navigation equipment like VOR/ILS and ADF;

- EIA Standard RS-422 allows the point-to-point data transfer from SAU to CSMU;

- EIA Standard RS-485 is used to multiplexing the information between control panels, transceivers/ transponder and remote display units.

Thanks to the implemented protocols, the industry standard RS-485 reached performances equivalent to MIL-STD-1553B at lower hardware cost.
Specific functions, which in the past required dedicated hardware resources, were implemented via software. Some examples of these functions are listed below:

- the Flight Director, that was originally a stand-alone analog computer, was replaced by a software module running in the Mission Processor;
- navigation sources and modes selection, which previously requested dedicated cockpit control panels, were provided by the MFD’s softkeys through format dependent labels;

- weapon selection and monitoring, originally implemented through a dedicated armament control panel, was provided by the SMS format in the Multifunction Display;

- specific devices like altitude/airspeed switches or dedicated engine throttle position microswitches were replaced by software controlled functions using shared information.

Furthermore, the MB-339CD avionics architecture allows for future implementation of new functions, simplified by the software on-board loading capability of the main avionics equipment (i.e., MP, MFD, EGI and EDAB).

3.3 Equipment

One of the driving criteria in the selection of the equipment integrated in the aircraft was the use of COTS units and, when this aim did not allow to comply with the operational requirements or military environmental constraints, the reuse of existing military off-the-shelf equipment. The development of customised equipment was therefore limited to those applications that required specific aircraft-dependent interfaces or with particular space constraints.

Customisation of existing equipment became a possible solution thanks to the capability of autonomously developing embedded application software modules, capable to meet system integration requirements.

Examples of COTS equipment included the VOR/ILS/MB navigation receiver and the ADF: they were general aviation units that were integrated using ARINC-429 interface in the Mission Processor (installed in the aircraft with specifically designed mounting trays to cover the vibration envelope).

The areas where reuse of existing units have been applied, are the following:

- Navigation sensors like TACAN, Air Data Computer and Radar Altimeter;

- Central processing equipment as the Mission Processor and the Data Transfer System/Digital Map Generator;

- Recording units like Video Recorder;

- Cockpit displays, including HUD and MFD.

The systems customised by application software were the EGI, the MP and the FDR; the EGI and the MP were controlled by an operational software specifically developed for the avionics system, while the FDR software was updated to meet the MB-339CD application-dependent interface requirements.

3.4 Components

At hardware level, the MB-339CD avionics showed that the most important goals of a military aircraft development program (i.e., growth potential of computing resources and reduction of size, weight and power), are conveniently achieved by employing electronic components and circuits derived by commercial and industrial applications.

COTS components were selected on the basis of technical suitability for the specific application, such as component temperature range, power and voltage rating. Furthermore, the components performance and reliability were continuously monitored through feedback to equipment manufacturers.

Several COTS component applications were adopted for the MB-339CD avionics system. These are briefly described below:

- all the equipment connected to the MIL-STD-1553 data bus used the same off-the-shelf bus transceiver chip in a configuration capable to cover both Remote Terminal and Bus Controller functions;

- all the CPUs embedded in the avionics units were COTS components with extended temperature range; no MIL-STD-1750 CPU was employed while a wide range of industrial CPU were used including: Motorola microcontroller 68332, Intel microprocessors 80960, 80C186, 80C196 and 80C51, Texas Instrument digital signal processor TMS 320C3X;

- the removable cartridge of the DTS included COTS solid state Flash memory with PCMCIA interface;

- the active matrix colour liquid crystal display of the MFD was a COTS component exhibiting full compliance with military requirements thanks to the ruggedized design process;

- the incremental Gray encoders used for the rotary cockpit controls were COTS components selected on the basis of resolution, power supply and reliability requirements compliance.

3.5 Test and Evaluation

COTS technology was applied not only to the on-board systems but also to the test, verification and evaluation tools including laboratory test equipment, avionics Rig and Flight Test Instrumentation.
In order to mitigate the obsolescence risk, all the equipment of the MB-339 CD avionics system were individually tested for acceptance using laboratory test sets based on PC's and commercial software packages. This approach allowed verifying the functionality of the units autonomously, before performing the actual integration tests performed at the avionics Rig.

The adopted avionics Rig was capable to reproduce the aircraft interfaces, to provide the test engineer with representative cockpit and man-machine interface, and to simulate real dynamic flight conditions using a 3-D flight simulator software package running on a PC.

The avionics Rig was used not only for testing and verification purposes, but also for pre-flight evaluation. Particularly, test pilots and engineers could evaluate the various functions of the avionics system and relevant man-machine interfaces, obtaining progressive refinement and optimisation of the various solutions and minimising costs by reducing the number of flight test sorties required.

The avionics Rig modular architecture and the extensive use of commercial hardware and software tools allowed easy implementation of the functions associated to the integration of new equipment.

Flight test activity, conducted on the prototype aircraft, was carried out by both company and Air Force test pilots to demonstrate the expected performances, functionalities and man-machine interfaces under real flight conditions. The prototype aircraft was equipped with state-of-the-art flight test instrumentation based on COTS acquisition and recording systems (e.g., Differential GPS, Magnetic Recorders and Telemetry Data Link).

3.6 Certification and Logistics Support

COTS integration demonstrated important benefits during the system life cycle and specific advantages in certification and product support. In fact, the certification process did not address individual COTS components, modules or subassemblies, as it was aimed at specific equipment functions. However, equipment certification credit was gained by establishing that the various components were selected on the basis of proven technical suitability for the intended application (e.g., component temperature range, power or voltage rating, quality control procedures of the component manufacturer and COTS availability/implementation in

similar applications). Furthermore, COTS derived products did not require additional custom engineering and support effort, because the commercial equipment manufacturers provided, as required, continuous assistance in solving obsolescence of electronic devices and circuits.

4. CONCLUSIONS

In this paper we have presented a living application of COTS equipment and components integration in a modern avionics architecture.

Particularly, we have attempted to emphasise the impact of a COTS approach on the various development phases of the MB-339CD advanced trainer aircraft.

A complete description of the new avionics has been provided and the criteria used in COTS integration have been described through several real examples covering different design areas of interest: system architecture, equipment selection and components usage.

The approach applied in the development of the MB-339CD avionics has yielded a state-of-the art and cost effective solution where the use of non-developmental equipment and COTS components has provided cost and schedule benefits reducing development risk and improving logistics supportability.

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Avoiding Obsolescence with a Low Cost Scalable Fault-Tolerant Computer Architecture.

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Overview

This new computer architecture can use anything from COTS (Commercial Off-The-Shelf) microcontrollers to the latest high-end processors. It is a distributed fault-tolerant architecture that is dynamically reconfigurable in the event of device failures, and is fully programmable in conventional high level languages. By using a simple two-level hierarchy with redundant control processors that configure the I/O (Input/Output) processor arrangement, even the failure of several processors will have no effect on data. An example is given of a real-time data acquisition system with a total cost for a 16 channel device with mixed sync/async and proprietary baud rates, of less than $500 in parts. This example system can be reconfigured to any arrangement of 16 or less serial interfaces.

The architecture is flexible and can be expanded into two levels: status, health and monitoring; and clustered I/O and processing. Additional expansion to a third level would add adaptive learning aspects. Each processor can be dynamically removed or replaced, and is designed to run a minimal amount of processor-specific software – about 1-2 kilobytes of code, which allows each new type of processor added to be configured to respond as a generic processor / CPU (Central Processing Unit). This facilitates the addition of new processors with a minimal amount of development. Present software may need to be modified to take full advantage of this architecture, although by using currently available distributed processor operating systems, most of the modifications can be avoided. The layout of the architecture allows both obsolete and state-of-the-art processors to work together, and transparent replacement of obsolete processors with newer ones. Some current software design methodologies can be applied to configuring the hardware architecture, such as CORBA – The architecture lends easily to Object Request Brokers - e.g. cluster CPU replacements can be specified by using Interface Definition Language -type description of CPU functionality, making it CORBA-like from a hardware perspective. Further development and acceptance of this architecture can lead to significant cost savings and mitigate obsolescence in future computer design.

Introduction

In general, CPU speeds increase faster than it is practical to replace them following Moore's law - speed doubling every 18 months or so.

Much of current software needs the increased speed for various reasons, which include poor coding practices and inefficiency. There are some of us, of course who yield to the marketing pressures to have the fastest processor commercially available for their own satisfaction. This is something like buying a Ferrari for the sole purpose of driving in funeral processions.

Due to the high cost of constantly upgrading CPUs to the most current, and the financial loss of decommissioning older processors after only two or three years of service, we need to find an effective means of mitigating this built-in obsolescence. The obvious solution would be re-use. There are several ways that we could do this. One would be to completely redesign the CPU's architecture, which would not be in the semiconductor manufacturer's best interest (but neither would effective re-use plans that reduced their future sales volume). Another way would be to design a computer architecture to allow the incorporation of both obsolete and current processors working together and allow future processors to just 'plug-in' to this architecture. We will define our goals for this architecture and details of implementation in the rest of this paper.

Goals:

1) A low-cost, upwardly scalable architecture that is built from current COTS processors. The scalability will allow future processors to work along with obsolete ones in a synergistic way.

2) Full fault-tolerance, where a processor(s) can be physically unplugged without losing data or overall functionality.

We want to do this with the most cost-saving approach. That would mean using obsolete processors in current equipment with state-of-the-art processors added to the architecture without large changes in software or hardware.

The objectives are to produce a seamless scalability between the old processor and new processors, as well as eliminating single point failures with the inherent redundancy of this architecture. Thus, expensive state-of-the-art updates, which rapidly become obsolete, can be replaced with a distributed architecture that supports both

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current, past and future processors working together in a synergistic manner.

The software embedded in each processor is easily maintained code which effectively translates each unique type of processor into a generic one in order to integrate it into this distributed architecture. That also allows each CPU to work with small but powerful real-time operating systems, as well as treat the processors as functional objects to be added or deleted from the distributed architecture.

Current Computing Systems:

In pre-COTS days, the CPU was designed for specific tasks. An example from about 1943 is Colossus, which was an electromechanical processor designed for code-breaking, and had its programming hardwired or set by patch panel jumpers. Later on, software written for processors allowed them to do general tasks and eventually multi-task. More recently, processors were designed for particular classes of problems, such as DSPs for signal processing, 32 / 64 bit CPUs for desktop PCs, and embedded controllers for small and medium scale device control.

We currently have a variety of COTS and proprietary systems that are either networked or stand-alone throughout the world. Typically, COTS life is 2-3 years. Large systems or mission computers, which may be based on COTS components, are usually obsolete by the time that they are fully deployed. This is due to a long (by computer state-of-the-art standards) initial life cycle development and deployment. Advanced proprietary or prototype systems usually have a longer life, but at a much greater cost.

High-end systems with multiple processors and / or special parallel processing schemes use specialized parallel algorithms that tend to lock in software to the specific architecture.

An example laboratory system is shown which replaced a proprietary architecture that had reached the end of its useful or maintainable life. A novel approach was taken to create a small scalable architecture based on COTS that maintained full functionality and most software compatibility with upward expandability.

Example System

This example system was originally a large rack-mounted VME-based system with proprietary boards. Additionally, the base system was obsolete and the proprietary boards had little or no supporting documentation. The objective here was to upgrade this system to a current scalable system for a hardware cost of less than $1000. The system should run a commercially or freely available operating system, and the upgrade should have minimal or no impact on functionality.

The new system should also be readily portable, so it can be designed into a briefcase with a laptop running Linux as a display unit, and a master controller board of about 30x30 CMS in size.

This master board would include the 16 data channels that the original equipment monitored and use four microcontrollers ("Basic Stamp" microcontrollers) to each acquire four channels of serial data at the proprietary baud rates, sync or async depending on channel. This board has the capability to add channels by just adding another microcontroller for each four channels.

(See Fig. 0)

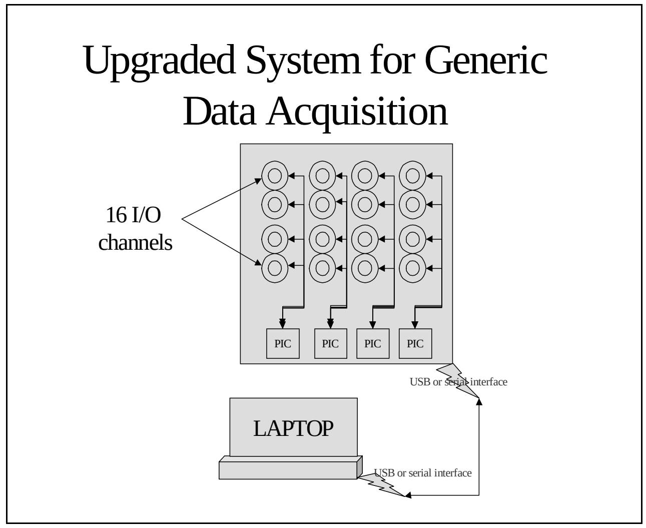

Figure 1 – the generic data acquisition system.

Since each PIC microcontroller chip is less than 4cm², the entire board and connectors is small and fits in the briefcase with the laptop computer. Additionally, each PIC microcontroller has several unused I/O channels that can be used as spares.

In summary:

(1) The large rackmount system was reduced in size to a briefcase.

(2) A rigid, non-expandable system was made upwardly scalable.

(3) The entire system is COTS based.

(4) The system costs less than $1000 in hardware (depending on the cost of the laptop –which could be an older model for $300-$500).

Improving the Original Concept:

Lets re-frame the example’s approach by using cheap CPUs in clusters to handle larger problems. Is this like the DIS (Distributed Interactive Simulation), currently renamed HLA (High Level Architecture), where networked systems participate in simulations from any location, and any system may deploy a real-time object into the simulation world such as an adversary or threat

platform? Not really, as that is meant to support the HLA's interface aspects for simulations.

We would want something that could handle generic distributed processing as well as specific aspects of computational processing, and perhaps parallel interfacing for multiple data channels. This architecture would be similar in function to the SETI@home web site, where you are offered a chance to participate in SETI's search and data processing as well as a nice screen saver. This is in exchange for allowing your computer to be used during idle time as one node in their distributed processing architecture to process their data. The SETI architecture is primarily a SIMD (Single Instruction Multiple Data) type of parallel machine, where a primary control machine is needed over all the node machines, and this could be a source for single-point failure. A comparison could also be made with our design to the Beowulf architecture, in that it can run on existing hardware, and can use open source software for the most part. There are differences, however in that the Beowulf cluster architecture is designed to run on private high speed LANs, and not over a distributed network. According to the founder of the Beowulf architecture, it will not be designed to run over the Internet, or a similar distributed approach. Again, Beowulf clustering is designed to have a master node control the cluster.

Lets consider the best ways to build an architecture from varied and possibly obsolete components. We would probably want a MIMD (Multiple Instruction Multiple Data) type architecture, or a SIMD / MIMD mix of clusters that can be dynamically reconfigured. In other words, each cluster could be SIMD for fault recovery, and the set of clusters would enable a MIMD architecture. We would also want to fall back to minimal configurations if we should lose many of the clusters. We will examine that first:

Start out with a small architecture, and call it level 0. This architecture may consist of only a few CPUs that have simple rules embedded into about 1-2 kilobytes of code for each processor. The code would also allow each processor to appear generic to the others, such that each one could use a common generic instruction set. There would be no need for a true operating system on each processor. These processors could be microcontrollers, DSPs or other embedded systems as well as high level CPUs. A single operating system would then run over all the processors.

A larger version, which we will call level 1, can use small kernel real-time operating systems for each processor, or just each cluster of processors.

The code embedded in each processor would be similar to the level 0 approach, and may have minor differences for classes of functionality, such as I/O clusters vs. status, health and management clusters. These classes could define clusters as particular types of objects with strong object models defined in tools such as UML, Rhapsody or Rational Rose for object modeling, as well as CORBA extensions.

The operating system running on each processor or cluster would have a small footprint (400k or so) such as in RTMX, PROSE and others, and be POSIX 1003.1b real-time extension compliant.

Fault Adaptation:

If one or more processors are unplugged or damaged, how can we handle this? What if a particular processor has an inherent exploitable vulnerability such that an attack from afar can succeed?

Figure 2 – How do we deal with Faults?

Both these situations call for some type of fault tolerance, usually not found in generic or COTS machines. We can, however determine an architecture that incorporates this scope of fault avoidance.

By using a clustered approach to disparate CPUs we can avoid these shortcomings inherent in conventional systems.

The design described here is optimal for multi-channel I/O intensive operations, but is not limited to that, and has far more diverse uses. An example of this would be low bandwidth but high levels of numerical calculations that work well in a distributed processing environment.

We define three levels of complexity in the architecture (more can be defined later). Each level has processors organized into clusters of two or three for fault avoidance. These clusters can act as a single processor if complete data recovery is mandated, and as such inter-processor communication shares data and processing so that any single processor failure will not affect data or processing capability. In some ways this is similar to the RAID aspect of redundant disks for critical data storage and recovery.

Example Level 0 architecture:

This consists of small clusters of redundant-functionality microcontrollers or standard CPUs that are not necessarily identical, each of which has several I/O channels, with a digital switch layer to isolate any major electrical faults. This way if the external devices that are being interfaced to have noisy data or unstable voltage fluctuations, the processors are not damaged. Since the monitor code executing on each microcontroller is almost identical (identical if same type / model of controller) and consists of a few kilobytes to make these generic in nature, any damage to, or physical removal of any processor does not affect the data or processing in any way. This code also monitors neighbor status and handles basic I/O functions.

We have a small and efficient real-time system, on which we can optionally load a distributed operating system. The operating system would treat each cluster as a single processor, with the embedded monitor code "translating" instructions to run as a generic processor.

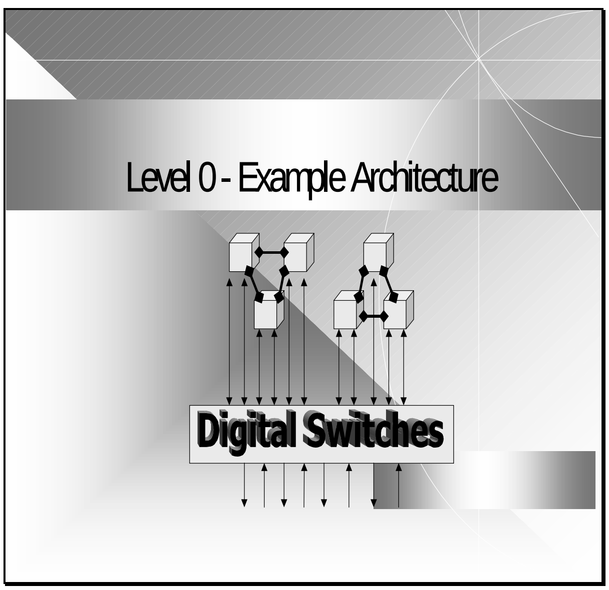

Figure 3 - a level 0 example

Level 0 Rules:

Details on the level 0 rules explain how we can accomplish our objectives for fault management, health monitoring, and generic processor functionality in a small (< 2 Kbytes) code space. For very different processor architectures some parts of this code would need to be modified to accommodate unique aspects. We define five rules that apply to the level 0 architecture, and also to varying degree to the higher levels as well:

<u>Rule 1:</u> *Relation* (intrinsic) - keep related I/O in localized cluster(s). On a small scale this would mean that I/O from a common or related source would be handled by one cluster, so that if a CPU failed, then its alternate(s) would take over for it and request another backup CPU while managing to save the data in temporary storage. By handling faults in this way, a race condition could be avoided which would occur if part of the data were in a non-local CPU when the one in the local cluster failed.

<u>Rule 2:</u> *Association* - direct data to associated destinations (process or memory block in common). This method of “chunking” data also mitigates similar race conditions, or skewed timing problems that were mentioned in rule 1.

<u>Rule 3:</u> *Selection* - "hot" or pre-selected runner-up processor affiliated with active processor in each cluster. This allows a pre-selected replacement for failed CPUs in a lossless manner. In situations where there are an odd number of processors after a fault, the lone CPU would affiliate with either the node of two CPUs under the heaviest load or a node of two CPUs in the closest proximity.

<u>Rule 4:</u> *Health* - IPC (inter-processor communication) or at least “ping” between affiliated processor and runner-up. This keeps a close watch on when a CPU needs replacement due to failure or when a lone CPU can join a cluster by following the *selection* rule above.

<u>Rule 5:</u> *Failure mode* - hunt for available processor if runner-up fails, and check for I/O saturation. Call for "help" from another cluster if saturated. This is the mode that a clustered CPU enters when it loses its associate CPU in the cluster.

We could apply all of this to the example architecture in Figure 1, without any significant increase in cost for hardware.

Level 1:

Inclusive of level 0, but level 1 has functionality divided over two or more layers of clusters - first layer is clustered I/O or CLIO. Next layer(s) is status health and management (SHAM). The original ruleset as well as new rulesets apply, defining more specific boundaries on SHAM and CLIO layers. Enhanced aspects are also applied, such as intelligent / adaptive configuration interfaces, to be used by level 2 architectures.

The functionality still remains overlapping with the level 0 architecture, so that if an entire layer is lost due to failure, the architecture will fall back to level 0 hopefully without any significant loss of data while maintaining full functionality.

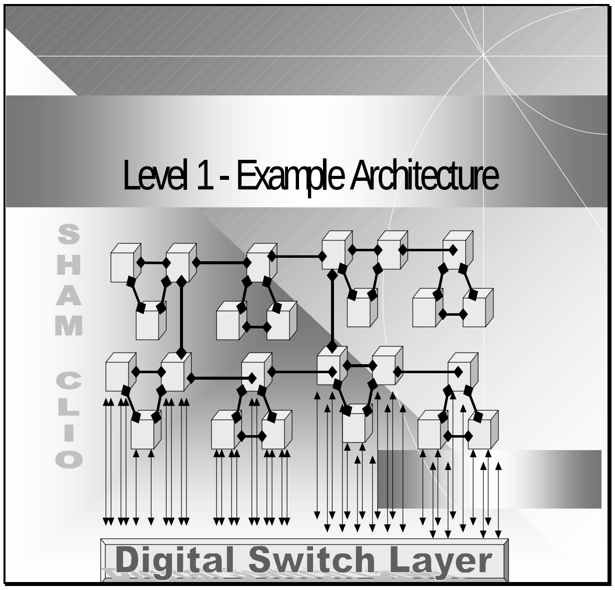

Figure 4 – a level 1 example

Example Level 1 Architecture:

As seen in the diagram, the same clustering is used in the level 1 design, but the clusters that handle I/O are in a separate layer from the status, health and management. The two layers communicate with each other similar to the single layer level 0 via inter-layer channels, and yet maintain the intra-layer and intra-processor communications as well. Inter-layer communications are kept short for the most part, unless a major reorganization of layers needs to take place. This minimizes overhead on interprocessor communication links.

Digital communication in and between layers could be accomplished by an internally incorporated USB interface for 809xx series microcontroller, or could be an Ethernet interface built into a microcontroller (I think somebody already has one out there...). That way each cluster could pick up a portion of the network load processing.

Keep in mind that these processors do not need to be state-of-the-art, but obsolete and inexpensive ones could suffice. Typical standard microcontrollers cost about $1-$2. Older PC CPUs cost $10-$30, and can have up to 50% of the maximum processing power available today.

Fault adaptation on intelligent multi-kernel clusters (Level 2):

This advanced version of the architecture can actively reconfigure itself for fault avoidance, and adapts to hostile attacks. An example would be an attack from a networked intelligent agent that focuses onto perceived weakness in the architecture, or even operating systems executing on it. The system would be able to compensate for and possibly repel future attacks. This is feasible because of the nature of a distributed system like this. If one or more layers handle adaptive learning, then it can behave like a neural network or other adaptive systems. The degree of complexity in the level 0 or level 1 architectures may not be sufficient to accomplish this. However, in this level 2, there are at least three layers, the first two handling the aspects of level 1, and additional layers the adaptive aspects.

Enhancing aspects of the level 2 paradigm can allow separate kernels to run on each node, with socket-based communication handling I/O and IPC.

Several real-time operating systems can exploit the benefits of this architecture. Two examples of operating systems that have excellent security built in are:

1) RTMX - this could run as 1 kernel per node. It exhibits the full Berkeley support for export, NFS and shared memory, and incorporates high level encryption. This has recently been donated to the OpenBSD project, as it is open source code. This means that in future releases of OpenBSD, the real-time portions of RTMX will be incorporated. If these future versions support a small kernel as in RTMX, then OpenBSD can also be a viable operating system for this architecture.

2) PROSE - Developed at Sandia Labs, this could function as 1 kernel per cluster or even layer, as the operating system supports a real-time kernel running over a multi-node network. This was to be certified by NSA to the B3 level.

Both of these can be placed into ROM for each processor or globally shared, as the entire kernel is less than 400 Kbytes in size. They are also both publicly available.

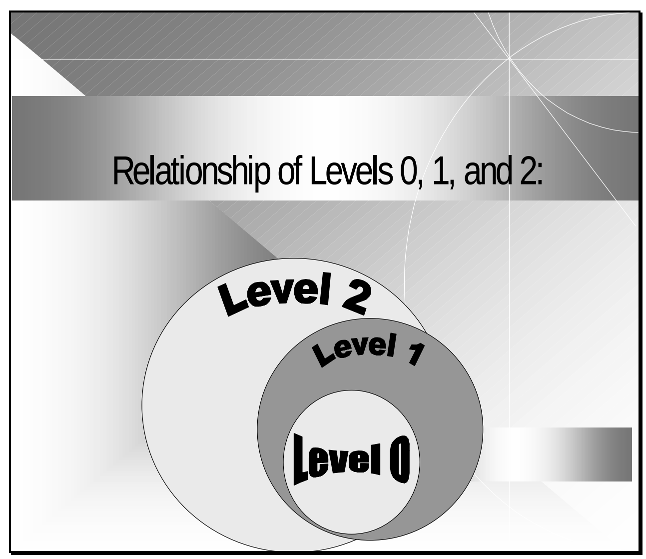

Figure 5 - Relationship between Levels

The relationship between the three levels just described is as subset / superset, where level 0 is a subset of level 1 and level 2, level 1 is for the most part a subset of level 2 with some minor exceptions that have to do with adaptive vs. non-adaptive fault management. The purpose of designing the architecture in this way is to allow full scalability between having a few CPUs form a level 0 to adding on more CPUs to the architecture over

time to eventually achieve level 2. Beyond level 2 can still be treated as a level 2 configuration, with enhanced functional features typical of a massively parallel distributed processor machine.

Perspectives and methodologies:

This distributed architecture is similar to a neural network in many ways, not least of which is its ability to adapt and self-organize in larger versions. An interesting aspect that would allow us far more control over the internal organizational interconnectivity would be to use tools from the software engineering world and take an object oriented approach. Currently, the object-oriented approach is applied only to software. For optimal benefits to be derived from object-oriented design, the methodology should be applied system-wide, i.e. to hardware module objects as well as software. We could then bring the hardware and software worlds together into an object based system paradigm.

The architecture described in this paper lends itself to this type of approach. If we treat these architectures as object models then we can use existing tools such as Rhapsody, which is designed to work in embedded systems and is a UML (Unified Modeling Language) visualizing environment with a built-in model checker. This can develop the common ruleset generation for each level, and possibly map layer connectivity.

Hardware layouts can be managed by a CORBA-like environment, with clustered CPU mappings defined by an IDL (interface definition language) and managed by an ORB (object request broker). The objective here is to accomplish a system-wide object-oriented design not just limited to software. Ultimately this may create a more consistent mapping of software processes onto hardware resources.

Finally, and for future research, a large-scale version of this may prove useful as an inexpensive alternative to the quantum computing environment of Shor & Lloyd (Bell Labs / MIT), at least until that becomes economically competitive.

Conclusion:

This distributed architecture is based on COTS systems and essentially does a re-use of obsolescent CPUs. The distributed architecture constructed can be done at minimal cost compared to state-of-the-art, or proprietary systems. It produces a robust architecture that is upwardly scalable, fault tolerant and dynamically reconfigurable so that mission critical data is preserved. The system constructed from this architecture can run real-time and is a distributed parallel computer. Essentially, it is a supercomputer built from obsolete and current components. The trade-off of reliability for extreme speed is done with distributed modularly defined clustering. By organizing the methodology of implementing this architecture into three levels that are based on the degree of functionality and complexity, and basing the core level on a set of intrinsic rules that govern fault related mitigation, we can construct a highly modular paradigm for distributed processing.

The modular design fits well with the concepts of OOD and use of UML for definition, and CORBA aspects such as ORB for hardware modules.

Further development of this architecture can result in defining a new standard to apply to distributed architectures. This standard would simplify hardware redesign through the modularity of an object-oriented hardware paradigm with tremendous cost saving benefits by re-use of existing low cost obsolescent processors.

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PROSE – parallel real-time operating system developed at Sandia Labs:
http://www.cs.sandia.gov/%7Erolf/puma/jrtos/

RTMX – real-time operating system that recently has been donated to OpenBSD organization:
(1) http://www.rtmx.com/
(2) http://www.openbsd.org/

SETI @Home - http://setiathome.ssl.berkeley.edu/

A Modular Signal Processing Architecture to Mitigate Obsolescence in Airborne Systems

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Summary

After providing an introduction to the obsolescence problem, this paper explains how the topic is handled to dated, using an airborne radar system development as an example. In this, the supplier primarily reacts on obsolete components with post design measures. In contrast to this a pro-active approach is suggested that starts with defining an architecture that eases the substitution of obsolete components and allows upgrades without involving major redesigns. This includes the need to safeguard the effort spend for developing and qualifying application software.
The article presents a modular structured signal processing architecture that employs COTS modules and standards. It discusses the ability of such an architecture to cope with the obsolescence problem by separating interfaces from processing units and applying COTS interface standards. Means of the designer are examined that allow to proactively design a processor that is likely to survive hardware and software component changes at minimum cost. Forming standard building blocks that encapsulate processing functions is presented as an approach that will considerably reduce the involved risk.

Situation Today

The Obsolescence Problem

Development and supply of todays digital components has been adapted to the needs of the commercial markets, especially to support mobile communication and consumer products, as these by far outnumber the required components in the defence industry. This affects both, the components availability and their capabilities.
The life cycle of telecommunication and consumer products, e.g. mobile telephones, ranges between 2 to 5 years, whereas the defence products show a life cycle time in the order of 20 years and more. Suppliers for key components like memory and microprocessors have life cycle times of about 2 to 4 years, adopted to their main customers. As a result, a defence product has to cope with the same component becoming obsolete in the order of about 5 to 10 times during the equipment life time. This will most likely start at the beginning of the product life cycle, i.e. during the definition and development phases.

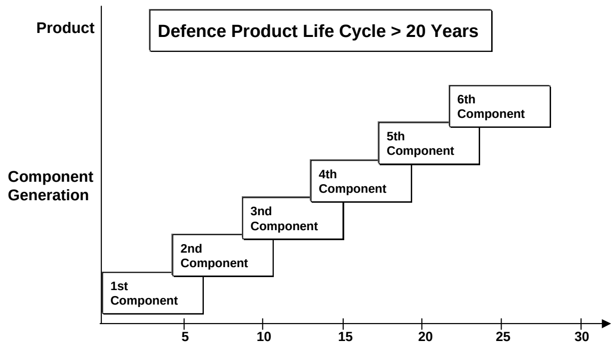

Figure 1: Equipment and Component Life Cycle

The virtue of such frequent component upgrades is a permanent enhancement in performance and functionality of components that includes low power consumption as the supply voltage levels drop. In the past, military applications drove the performance and functional specification of digital components. This has changed, as the telecommunication and consumer markets produce nowadays complex products as well, with a need for high performance, low cost components.
The major differences are the harsh environmental conditions a component has to sustain in a defence product as well as the product reliability it has to support.
For airborne applications in an military fighter aircraft, the most severe environmental conditions include:

- Wide temperature range of both the ambient and the cooling air (if any).
- Humidity, especially when high temperature and pressure gradients are to be faced.
- Mechanical shock and vibrations

MIL standard components have been able to cope with these conditions, as they were designed for them.

Paper presented at the RTO SCI Symposium on "Strategies to Mitigate Obsolescence in Defense Systems Using Commercial Components", held in Budapest, Hungary, 23-25 October 2000, and published in RTO MP-072.

However, due to the rapidly diminishing share of military applications on the semiconductor market, MIL standard components are vanishing.
Industrial, and especially commercial grade components specifications do however not consider these environmental conditions. As they are designed for cheap mass production, their design includes:

- Plastic encapsulated modules (PEM)
- Low voltage supply

Since the life cycle of commercial products is much shorter compared to military avionics equipment, the required product reliability can be lower. In military applications a primary failure rate of only a few occasions per 1000 operating hours can be accepted. Equipment that is involved in flight safety has to fulfil even more stringent reliability requirements.
Whether the predicted reliability of equipment applying industrial / commercial components suffices depends very much on the prediction method. MIL Handbook 217 is generally considered to be too pessimistic compared to other methods.
PEMs may not only reduce the equipment reliability in severe environmental conditions, but also require careful storage to avoid penetrating humidity and pin corrosion. The same level of care should be taken during production to avoid e.g. contact with perspiration.
Figure 2 summarises the facets of the obsolescence problem as outlined above. Component suitability may be tackled by design methods, of which some are outlined later in this paper. Regardless of those, the problem of component availability and high frequency of upgrades remains and will most likely cause a number of serious impacts on any military development project:

- Production of military products will be more difficult as the list of components will change frequently during series production.
- It becomes increasingly difficult to procure spare components.
- Permanent and frequent design activities are necessary during series production. Obsolete components will have to be faced already during the definition and development phases.
- An ever increasing gap between the technology used in commercial products and the technology applied in military applications.
- The inevitable re-designs of processing H/W require the transfer of the highly expensive application S/W on new processing platforms.
- The error in programme cost estimates will increase as the effort for future obsolescence removal activities is difficult to estimate, but a significant factor.

All of the above will increase the product cost over the product life time. However, with methods, which are described in the following sections, these costs could be minimised (except for the last bullet above, which will not be covered in this paper).

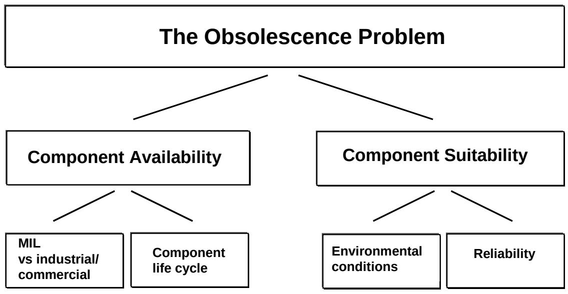

Figure 2: Obsolescence Problem Tree

Today’s Strategy

Avionics systems coming today to series production are based on developments in the 90ties. In the digital and especially in the processing area they were driven by thoughts as

- Minimise the number of different components and therefore maximise the amount of equal components for series production
  - Use of “Common Standard Boards”
  - Increase production quantity of equal boards with equal processes
- If required, support the processing power by dedicated ASIC’s, e. g. as hardware accelerators for mathematical operations

The cycles from development to production was planned as phased approach with

- Development Phase
- Qualification Phase (which may be part of the former phase)
- Production Investment Phase to prepare the necessary facilities and tooling for series production
- Series Phase

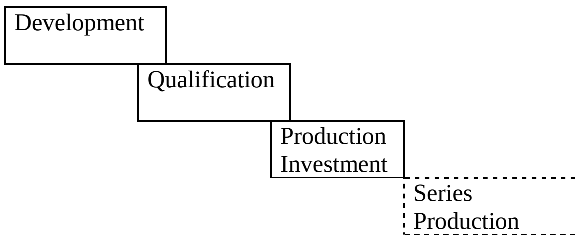

Figure 3: Equipment Phases vs. Time

Keeping in mind the development duration for military avionics products of approximately 8 to 10 years and the progress made in technology between, the supplier is faced with the challenge that the just developed and qualified product is not manufacturable. This is extremely valid in the processor and ASIC area were, for example, the physical structures had shrinked from 1.5 µm down to 0.35 µm and below in the meantime. Therefore, most of the ASICs became obsolete.
It had become necessary to expand the Production Investment Phase by an additional development phase to mitigate known obsolescence at time of starting the Production Investment activities. This results also in an

additional (and at least partly) re- qualification of the modified equipment.

Unfortunately, the injection of a re- design cycle mitigates the obsolescence problem only at the moment, but not in medium and long term aspects. With the ongoing strong decrease in the availability of military components forced by

- disappearing of key vendors from the military market (e.g. LSI Logic),
- company sell offs in the ASIC business (e.g. GEC Plessey, TEMIC),
- change in base technologies (e.g. ECL supersedes CMOS, 3.x V replaces 5.0 V),

the obsolescence problem overhauled the re- design and is back again. This situation is known in the mass market but indeed new for military developments.

Therefore, to come to a production phase the following options are possible and request a careful component by component observation

- Re-Design
  If a certain amount of components is obsolete or marked to become obsolete in shorter time, a re-design is necessary to mitigate the obsolescence risk for the start phase of Series Production.
- Re-Specification
  Components specified according to a very high quality level should be observed if a lower qualification level could be accepted and if the component is available at this level (e.g. QPL component replaced by MIL 883 type).
- LastTimeBuy
  Considering the time consumed for a re- design / re-spin of complex key components (e. g. ASICs) it should be necessary to perform a Last Time Buy. This possibility should also be selected if a component becomes obsolete after start of re- design and could not be included in this cycle.

Any of the above discussed possibilities must be chosen after careful observation regarding

- Schedule
- Risk
- Impending re- qualification

Experience in an avionics project shows that after finalisation of the development phase

- 75 % of the components are still active
- 11 % of the components require a re- specification
- 1 % of the components require a re- design
- 13 % of the components require Last Time Buy

The Last Time Buy number in this example is quite high as the design key elements are ASIC's which become obsolete by reasons discussed above.

In any case, a sophisticated obsolescence management has to be established to observe the relevant component market and gain early recognition of upcoming component obsolescence. As efficient as the established obsolescence process in each company or in consortia is, it mainly suffers from

- Availability of Last Time Buy Warnings
  Not all component vendors issue early warnings for upcoming obsolescence. Today's practice shows that components are becoming obsolete without public notice. The problem is recognised by the user at time of placing an additional / new order.
- Number of avionics systems to be built is not fixed.
  Forced by the existing lack of funding at the military purchasers the total number of items to be built is not fixed at production start. This means that the suppliers keep the risk in definition of the number of systems to be built as well as for the required logistic spares (item and component spares)
- Financial penalties
  Last time buy of components bind a not small amount of money in a very early phase of Series Production with all resulting penalties for the financial backer. Note that not seldom the equipment manufacturer has to take the burden to finance this stock.
- Technical penalties
  Long time storage of components may influence the processability in terms of e. g. solderability. Whilst in the early 90ties only logistic stock components had to be prepared for long term storage and stored in special stocks (protective gas environment) nowadays production and spare components have to be protected. This additional effort enhances also the overall costs.

Applying above principles to an existing avionics project which was developed in the 90ties and comes today to first Series Production deliveries, the financial effort could be characterised by

- Development Phase   100 %
- Obsolescence driven re- designs: 7 % of the Development Phase during Production Investment Phase
- Last Time Buys
  a) Not re- designed key components: 5 % of the Development Phase
  b) Upcoming obsolescence after Re- designs: 1 % of the Development Phase

The experience from the example project could be summarized by

- Obsolescence Management and mitigation must start with the Development Phase
- Last Time Buy of (at least) components is opportune
- A re- design cycle between Development / Qualification and Series Production forced by obsolescence is necessary

Revised Approach

All of the current methods to tackle the obsolescence problem as outline above, start once the equipment design is finished and components become unavailable. During the 80's and early 90's the electronic component selection process in military airborne applications was mainly driven by the requirement to use MIL standard components, preferably with a second source.

Architectural and design decisions were not influenced by the risk of diminishing manufacturing sources (DMS).
As the obsolescence problem starts to become the primary reason for re-designs and additional cost of ownership, the obsolescence issue needs to become an integral part of the equipment definition and development phase.
It is estimated, that about 70 to 80 percent of the overall product costs are committed during the first 20 percent of the development cycle. Hence, guidelines are required, that pro-actively address the DMS problem at the start of an equipment life cycle, when an equipment architecture is defined.
An architecture needs to be established, that minimises the re-design effort and duration once a component becomes obsolete. For this, an 'open architecture' is preferred, that supports established standards. Obviously, such an approach has the potential, to support future upgrades driven by the desire for performance and functional enhancements.
With the architecture being prepared for future obsolescence driven activities, the next step is to include the issue of DMS into the focus of the design activities of a new product. Use of commercial and industrial grade components, life cycle projection and careful environmental design are amongst the topics to be considered during the design process.
Both, architectural and design activities need to be embedded into a permanent obsolescence management process, that becomes part of the project management.

MSP2 - An Architecture Proposal

The Modular Signal Processor (MSP2) is being developed in a proprietary funded project that was started in 1998 at EADS, Airborne Systems in Ulm to build up a basis for a family of signal and data processors for military airborne applications. It is an evolution of the MSP system that was successfully applied in a number of military projects. MSP2 has now successfully passed the acceptance test phase.
A typical processor for a military airborne application consists of the following MSP2 parts:

- Signal Processing Module (SPM)
- Data Processing Module (DPM)
- General Purpose I/O
- Aircraft Interface
- Fibre Channel Network
- Optical Backplane

It is intended to be a processing platform that is scaleable in terms of form factor, processing power, and communication bandwidth. A typical MSP2 system is shown in Figure 4.

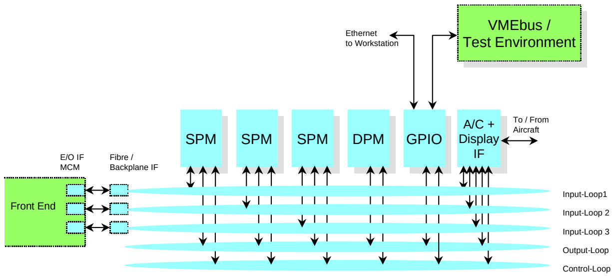

Figure 4: Typical MSP2 System

The interconnection between multiple Processing Modules (SPMs, DPMs, etc.) is achieved by linking the Fibre Channel Interfaces (FCIs) of several modules, either via discrete connections (coax cable or optical fibre) or via an optical backplane. These links are always implemented as loops. A typical system consists of several loops. The data exchange between different loops is done via the Routing capability on the Processing Modules.
A Processing Module (PM) consists of the following Building Blocks (see Figure 5):

- Processing Element (PE)
- Fibre Channel Interface (FCI)
- Module Support Unit (MSU)
- Routing Network

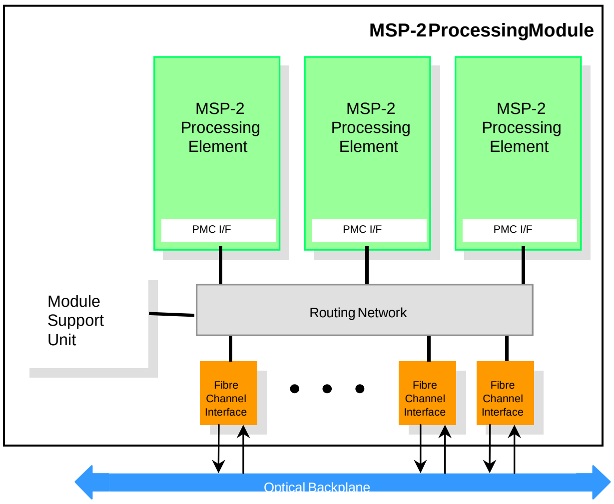

Figure 5: MSP 2 Module Architecture

The first implementation of a Processing Element are the Signal Processing Elements (SPEs) which are currently realised as PCI Mezzanine Card (PMC) modules. Hence the PM provides PMC slots for the mounting of the PEs. Off-the-shelf PMC modules may also be mounted on such a slot. Currently, the SPE is based on the Texas Instruments DSP TMS 320C6701 which provides a nominal throughput of 1 Gflop.
The Module Support Unit consists of a PowerQUICC Microprocessor, associated memories and a PCI-interface chip. The main functions of the MSU are: PM management including Built-In Test (BIT) and Fault Log, as well as the control of the intra-module data

transfer (between the PEs) and the inter-module data transfer (between PMs via the FCIs).
The Fibre Channel Interface provides the external interface to the PM. They are either connected to an optical backplane or to discrete connections such as coax cable or optical fibre. A first variant of the FCI has been produced as PMC module with discrete fibre connectors. Next generations will be an integrated part of the Processing Module.
The Routing Network provides the on-board interconnections between MSU, all PEs, and the FCIs. It consists of several PCI busses and PCI bridges.
The Optical Backplane, in conjunction with the optical tranceivers of the FCI, provides the board to board interconnection. A combination of free space and guided wave transmission is realised.
In order to achieve a modular design, the MSP2 architecture has been structured into Building Blocks that can be considered as the smallest entities of the MSP2. In fact, by varying the number of Building blocks and the number of modules, the MSP2 architecture is scalable and can be adapted to the needs of a specific project. Those Building Blocks are: Fibre Channel Interface, Module Support Unit, and Signal Processing Element. They all have a PCI bus interface in common. Other Building Blocks are to be added at a later stage, e.g. a Data Processing Element. Figure 6 depicts a family tree of the MSP2 architecture that show the modular design of it.

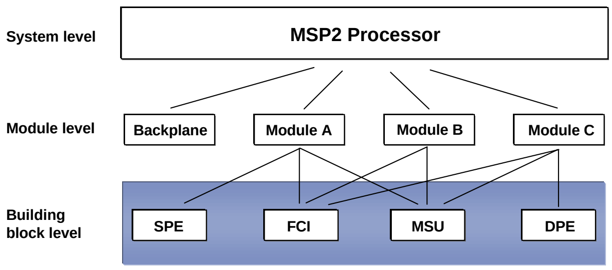

Figure 6: MSP2 Family Tree

Software for the MSP2 will be organised in different layer as shown in Figure 7, starting with the Board Support Package. This layer not only includes the necessary drivers but also the system management software that organises tasks like power up, system configuration, data transmissions, and build in test.
A COTS operating system forms the next layer, which will be separated from the application software by a ASAAC compliant APOS layer.

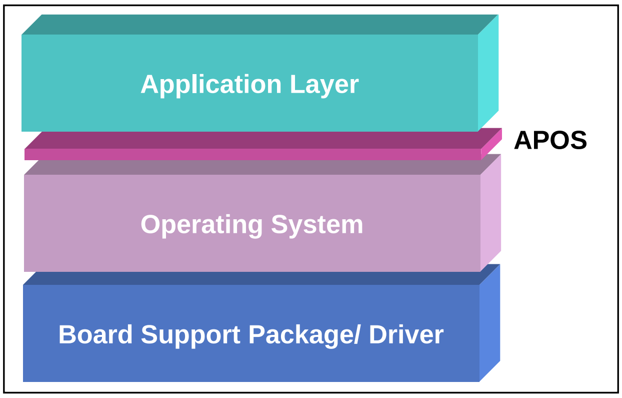

Figure 7: Software Layered Structure

Blueprints are used in order to map the application to the MSP-2 hardware. Blueprints present logical system descriptions using a standard format, thus providing a means for changing the system characteristics without having to change the application or operating system code. Blueprints are used for an application specific system design and for run-time system configuration purposes. In detail, Blueprints are broken down into the following three categories:

- Application Blueprints which formally describe an application’s characteristic, e.g. its decomposition into processes, its internal states, its performance parameter, its related communication elements.
- Resource Blueprints which formally describe the logical representation of hardware resources.
- System Blueprints which formally describe system integration and configuration decisions for a specific implementation of an MSP-2 system. This includes mapping information by means of relations between applications and resources, e.g. system state transition tables, process scheduling tables, communication channel assignments

Architectural Features that mitigate Obsolescence

Modular Concept

Forming a modular structure as in the MSP2 architecture carries a number of advantages with respect to obsolescence.
The most obvious is the efficiency improvement during the development. Once a building block has been designed and tested, it can be copied by a community of users, i.e. the Module Designers, that do no longer have to repeat the same development and verification tasks. This will lead to a hardware design library which can grow and mature. This level of modularity is achieved by separating the operational functionality of a module from the actual hardware resources/design.
Once a component on a building block starts to decline on its life cycle, re-design activities unavoidably have to be started to ensure the continuing availability of the affected building block. However, in contrast to the past

approach, that caused a re-design effort in every instance the obsolete component was used, the modular approach allows to concentrate the effort on one building block, including test and qualification. Once the building block re-design is complete, it can be copied to every module that applies this building block, with only a moderate qualification effort on module level.
Applying a modular approach as for the MSP2 processor also reduces the number of different components used in the airborne equipment. This allows to concentrate the component selection process on a reduced variety of components and eases the obsolescence management process.

Standard Interfaces:

The MSP2 architecture is based on two interface standards. On the modules, parallel buses in accordance with the PCI standard are used. The primary interface between modules is based on the Fibre Channel standard. Both of these standards can be considered as well established and 'state of practice'.
Using PCI as the standard interface of the building blocks allows the building blocks to be exchangeable. For example, a signal processing building block can be exchanged by a data processing building block without major modifications to the rest of the module.
Encapsulating hardware processing elements in that way, using a standard interface, can be considered as a significant step forward to an architecture that is supportive with respect to later obsolescence removal. The building block design becomes transparent to the rest of the module. Hence, changes to the building block driven by obsolescence, even the exchange of a processing chip set, are feasible without major impact on the rest of the module. For example, the signal processing building block currently applies the TI C6701 DSP. Moving to a different Signal Processor type if required due to obsolescence or performance reasons is considered to be possible without affecting the MSU.
Carrying the same idea one step further results in a similar approach when it comes to the application software. Due to the need for high signal processing throughputs, application software in past airborne radars was closely linked with the available hardware resources. Algorithms, requiring fast computation, were reflected in hardware designs, e.g. ASICs and machine code was used as the most effective way of programming with respect to throughput.
However, obsolescence had to be faced, not only the hardware needed to be modified, but also the application software was seriously affected. Since the signal processing software development in military airborne equipment such as a radar can easily exceed one third of the overall development costs, safeguarding this effort is of imminent importance.
With more and more powerful DSPs and PowerPCs becoming available, the emphasis of software development shifts from being effective in terms of throughput towards the need to reduce the software development effort.
Hence, the software for the MSP2 is organised in layers as outlined above, in an attempt to establish standard interfaces. All the different software layers, i.e. board support package, operating system and APOS ensure, that the hardware resources are transparent to the application software. Moreover, APOS ensures, that even the operating system may be exchanged without significant re-work of the application software.
APOS as it was established in the ASAAC programme translates the services provided by an underlying commercial operating system into a standard set of services that can be used by the application software.
Using standard interfaces also makes the use of COTS products possible. In the case of the MSP2, such COTS can be a processing building block, that interfaces with the module via a PMC connector. Application of such COTS modules can be a solution when an early A-Model prototype is required, e.g. to support software development. Using PMC modules in fighter aircraft avionics is currently not envisaged due to the high vibration levels that occur. Other areas of COTS application include the operating system and software libraries.
As it comes to test equipment, the use of standard interfaces offers again an advantage, since readily available COTS test equipment can more easily be used and more expensive STTE avoided, for which obsolete components would be a problem again. Primary test interfaces of the MSP2 are Ethernet, Fibre Channel in conjunction with PC, JTAG and a Fibre channel to VME bus adaptation in order to open the access to a variety VMEbus based test equipment.

As described above, the decreasing component supply voltage level are a primary source for trouble when it comes to obsolescence driven re-designs. As explained in Ref. X, no standard voltage can be foreseen as in the sense the 5.0 volts have been. Solutions to the problem include a dedicated power supply as part of the re-design. However, this need to fit into the power and cooling budget of the obsolete design.
For a new architecture a new approach is suggested. In that the aircraft supplied AC is first converted to DC of some tens of volts in a primary power supply. This is then routed to distributed power supply modules, if the distance between the modules and their total number prohibits direct low voltage delivery. DC/DC voltage level is performed and a standard voltage level is supplied to each module. There are power supply building blocks on each module, that further convert the voltage level to what ever is needed by the components.
In order to be flexible, the power supply building block output voltages are to be programmable in a range of about 1 – 5 volts. Care needs to be taken of the efficiency o such power supply building blocks, as it is likely to increase the dissipated heat of a module significantly.

Design Features that mitigate Obsolescence

Environmental Issues

As outlined above, using commercial or industrial grade components in a military airborne environment, e.g. a fighter aircraft results in a number of environmental issues to be addressed.

The most obvious is the temperature range, the components have to sustain. Regardless of the cooling mechanism, i.e. forced air cooling or convection cooling, the desired high processing power per volume most likely causes high case temperatures. Thermal vias and heat pipes are amongst the known means to mitigate the thermal load of hot components and avoid hot spots.

Another strategy to prevent thermal stress from COTS components is to adopt the available processing power to the needs of the operation where possible. For example, the avionics of a fighter aircraft might be stressed most on the ground, where no conditioned air is available, as the engines are off. In such a situation, most of the avionics equipment may not be required to be fully functional, except for the cyclic self test. Hence, the majority of the processing of the MSP2 can be switched to a ‘sleep’ mode with only a fraction of the normal heat being dissipated.

A more radical approach towards the use of industrial / commercial grade components and boards includes provisions to drastically soften the environmental conditions at all. This may include a ‘hotel room’ environment which protects the components from the environmental extreme. In order to control the thermal conditions, extra heating / cooling equipment needs to be in place. At least in military aerospace applications the system designer is very much confined with power, weight, and volume. Hence, a centralised, high performance environmental control system is needed, which also takes care of humidity. Other features of the hotel room environment include shock absorbers to dampen the mechanical stress from vibrations and shock, and sealed housing, to avoid the penetration of sand, dust, and chemicals.

As the humidity is beside cooling the most critical environmental aspect for PEM components, a lot of effort is put into the development of special coating of critical components or even a complete board. Recently developed coating materials and processes (DaimlerChrysler Research) reduce the diffusion of water to significantly less than 10 % compared with un-coated PEM components.

Providing a hotel room environment might be an option, where it is permitted by the available budgets for primary power, weight, and volume.

There is a temptation to use commercial grade components outside their environmental specifications, as they are from the same die as their military counterparts. However, there is no guarantee, that this will be the case at the next re-design and the equipment designer will be given no notification about any change in the component production process, that could cause the component not to perform at extended temperatures.

Component Selection

Throughout the MSP2 project, care has been taken to what components are to be used. Although commercial grade components have been applied when building functional A Models, the design has been driven by the desire, to minimise the use of commercial components, and rely on manufacturer with an expressed interest in the military market.

QML provides a performance based specification of COTS components that are designed to meet the needs of military applications. Components that fulfil this specification are preferred for various reasons: QML components are more likely to be supported for an extended period of time compared to commercial components, which are driven by the dynamic commercial market. QML manufactures also provide the essential services for an effective obsolescence management, e.g. configuration control and change notifications. QML devices work within a broad temperature range, that allows their application in military aircraft.

The major drawback of going QML is the restricted choice of components. In fact, two of the more significant components used in the MSP2 can be obtained only in a commercial temperature range.

Amongst the options for remedy is an up-screening of commercial components. However, this is thought to be a very risky approach, since it is generally not supported by the original manufacturer, which most likely results in a poor test coverage when it comes to more complex ICs. It will also cause a liability problem if a catastrophic failure happens as the IC manufacturer nowadays protect themselves with disclaimers for their commercial products.

A more elegant approach is the use of FPGAs as a hardware platform that is more flexible and widely available. VHDL as the programming language is well established and will allow a design of the required functionality, that is for the most part independent of the hardware, provided that the FPGA provides the required features / performance. Although, programming the design in VHDL might be initially more expensive, the gained independence from a particular component vendor might be worth the effort, when it comes to obsolescence. Moving from one FPGA to the next generation might only require a limited re-design of the PCB layout and porting the VHDL code. Hence, this approach is not only attractive if no component meets the environmental specification, but also to reduce the life cycle cost in case of obsolescence.

Finally, when a component needs to be selected, it needs to be considered, at what point in its life cycle a component is. It is a mistake to believe, that a component has a low risk of obsolescence, if it is at the beginning of its life cycle. In fact, the risk will be high that a newly introduced device will be removed from the market due to e.g. lack of success. It is much safer, to

choose components, that start to be ‘state of practice’, especially for components that affect the architecture, i.e. interfaces.

Conclusion

System designer for military avionics will be faced with components becoming frequently obsolete. This cannot solely be longer solved by traditional methods including last time buy. Frequent design updates will be part of the future business, requiring a pre-planned product improvement roadmap.

In order to reduce the involved effort, the EADS MSP2 processor development has successfully applied architectural and design measures right from the start of the project. These include a strictly modular software and hardware architecture and the use of ‘state of practice’ standards.

Application of commercial components is seen as being unavoidable, and hence the creation of a moderate thermal and mechanical environment (i.e. ‘hotel room’) will mean a major challenge for the design of future military airborne equipment.

None of the above measures can solve the obsolescence problem on its own, but needs to be embedded in a obsolescence management process.

Planning For Change With A Holistic View Of The System

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Summary. The example of obsolescence which perhaps comes most readily to mind is that of electronic components that are no longer available. However, this is just a special case of the more general form of obsolescence that arises when a system no longer provides an adequate solution to a user's problem. This may arise because the problem has changed or because the solution (the system) has, in some way. In practice, both the problem and solution are changing continuously and asynchronously. The approach to obsolescence management proposed here depends on recognising and planning for this change. In essence, it involves looking forward to how the demands on the system and the technology that provides its capability may both change. Simulation is a crucial tool in doing this. In the light of the understanding of expected changes, the design of the current system is arranged to facilitate transition to the modified system and a change plan is produced. This paper also looks briefly at the impact of the proposed approach on the broader system engineering activities and the commitment it requires from the system's customer.

Background to Paper. The Defence Evaluation and Research Agency (DERA) is the prime source of research for the UK Ministry of Defence (MOD), and also provides a major source of independent advice to MOD during all stages of systems procurement.

The Systems and Software Engineering Centre (SEC) is a relatively new body within DERA, being established in 1994 to act as a focus for professional software (and soon after, systems) engineering within DERA. The majority of its complement of about 260 staff have an industrial background.

The SEC has responsibility for the systems and software standards and practices used across DERA (which has a staff of around 11,000). It provides the editor for the draft ISO standard (ISO15288) on systems engineering and is influential in setting the systems engineering direction of MOD's procurement arm, the Defence Procurement Agency (DPA). It provides systems and software engineering support to a wide range of programmes within DPA. The SEC is also leading in the field of capability assessment and evaluation, eg in developing and applying various Capability Maturity Models (CMMs). The author is the SEC's Technical Manager.

Despite this background, it should be made clear that this paper does not constitute the results from a MOD-funded research programme, nor does it represent the official view of MOD, DERA or the SEC. Rather it captures the personal views and thinking of the author. However, the author is pleased to acknowledge the rich source of ideas he has encountered in the SEC, DERA, MOD, Defence Scientific Advisory Council (DSAC) working parties and other contexts.

Introduction. Obsolescence happens because the world changes. Today , this change happens more and more rapidly. Sometimes the change is predictable (such as the increase in power of processor chips), sometimes it is rather more unexpected and of a more dubious nature (eg, to take a completely different domain, the disruption caused by the rapid rise - and sometimes rapid fall - of "dot com" companies on the stock market).

Defence systems exist in this volatile world and yet in many ways are antithetic to it. They have a long "gestation" period and are expected to be in use for extended periods. It is clear that a way to mitigate the impact of changes is required.

Many approaches are possible, all of which make some contribution. Well known techniques include attempting to create system architectures in which components can easily be replaced when appropriate, through concepts such as modularisation, layering, fixed and open interfaces, and standardisation.

This paper considers a complementary approach based on simulated "virtual" systems. It is a generic approach that supports, but is not restricted to, the particular problem of managing obsolescence in electronic components.

Paper presented at the RTO SCI Symposium on "Strategies to Mitigate Obsolescence in Defense Systems Using Commercial Components", held in Budapest, Hungary, 23-25 October 2000, and published in RTO MP-072.

The Nature of Obsolescence. It is helpful to consider some basic questions:

- What is obsolescence?
- What becomes obsolete?
- Why do things become obsolete?

Obsolescence. Obsolescence is the act of becoming obsolete. The dictionary defines obsolete as "no longer functional". However, we can extend and clarify this by considering that an item is obsolete when both of the following are true:

- It no longer meets the user's need (we assume it once did!)
- It is not possible to make it do so without considerable effort – if at all

A very simple case of failing to meet the user's need occurs when an item ceases to function, and a simple reason for not being able to remedy this in an easy way is if the item is no longer available. This is the classic electronic component obsolescence situation, and is perhaps the easiest to consider, but it is far from being the only way in which obsolescence can occur.

In many cases, obsolescence is a gradual process. As time passes, it may well be that the item diverges more and more from what the user needs and at the same time it becomes more and more difficult to bridge this gap.

It is also worth noting that an item can be obsolete in one context (eg in respect to one user's needs) while not being so in another.

What become obsolete? It is important to note that obsolescence strikes at all levels, from the smallest (electronic) component to a complete system. Clearly, if a component becomes obsolete, so often does the (sub)system of which it forms a part, but equally a system can become obsolete while each of its constituents remains current (in some context at least). If the collection of components and their interaction no longer provide the functionality and performance required, and it is not simple to change or directly replace them, then the system is obsolete.

Hardware components can become obsolete because they are no longer available and cease to provide the necessary features, either through failure or because more is now needed of them than originally. COTS software items too can become obsolete in the same sort of way (although failure is less likely). However, bespoke software can also be obsolete if changing it, while possible in theory, becomes too difficult, costly and risky to be worthwhile.

Why do items become obsolete? Perhaps the most obvious cases of obsolescence occur within electronics. Anybody who owns a PC at home is only too aware that even a top-of-the-range machine purchased three years ago is now likely to be considered out of date, with little residual re-sale value. It may still be possible to do most of what is required of it, but now very slowly by today's standards. Virtually every item (processor, bus, memory, disk, CD drive, etc) has seen significant enhancement over the period. In some cases, there are new capabilities that are just not available on the "old" machine (eg DVD).

In a lot of ways, though, the machine is not obsolete because it lacks a fundamental capability, but because it lacks enough of what it does have (not enough processor power, not enough RAM, not enough disk space, not enough graphics speed, etc). Furthermore, while in principle most of these aspects could be upgraded, the cost would comfortably exceed the price of a brand new replacement.

And why is what was enough three years ago no longer sufficient? Largely because expectations have increased - the expectations of the end user and the expectations of the software writer, who now assumes a basic configuration that is valid today but was not so three years ago. It is interesting to note that this software is a COTS item - so COTS is helping create obsolescence not prevent it!

Systems can also become obsolete because they simply do not provide the functionality that is required in a changing environment (if they ever did!). Most changes in environment that cause obsolescence are gradual; the change is continuous. However, some changes are much more abrupt. Betamax home video recorders became obsolete very rapidly once the VHS-Beta format battle was lost, for example.

In addition, systems become obsolete simply because failures (primarily in hardware, but software can be affected too) happen and there is no reasonable source of spares with which to effect a repair.

The poor owner of the PC and the video recorder is totally powerless to prevent his systems being made obsolete by external, "wide world" forces over which he has no control. The best he can to do is aim to predict correctly where the future is leading (eg VHS) and take reasonable steps to ensure he can follow (eg ensuring upgrade potential in his PC, such as spare card slots and bays).

Obsolescence in the defence world. Of course, these same pressures and issues apply to defence systems. They too become obsolete for two basic reasons:

1. The environment in which the system acts has changed in such a way that it can no longer offer adequate performance

2. The system is subject to faults that can no longer be repaired easily because of a lack of suitable spares/skills/facilities

Again, since the defence world is ever-less-important on a global scale - particularly in the most rapidly changing areas such as computing and communications - the obsolescence may be increased by COTS items.

Naturally, the procurers and owners of systems - like the PC/video buyer - attempt to minimise these risks. However, the emphasis is often on the initial procured system and some rather general upgrade capability (eg not consuming more than 50% of the processor power), rather than on more detailed forward planning.

It is not suggested here that the future is currently ignored when procuring a typical system, or that consideration of the future does not get reflected in non-functional requirements such as for extensibility. However, the approach outlined here does perhaps differ from that widely adopted in its emphasis on:

- A broad view of the future that encompasses the physical system, the user, the method of use, etc
- An in-depth (at least to the degree that is appropriate) exploration of the future
- Explicit capture and maintenance of the future-oriented material

Planning for Change. Obsolescence is caused by change, and its impact can only be reduced by anticipating and accommodating change. Change is natural and inevitable, and it is futile to ignore it. Procurement approaches that are predicated on fixed and detailed up-front system specifications, rigid fixed-price contracts, and a fear of so-called "requirements creep", come close to emulating King Canute[1].

Rather, the need is to recognise change and cater for it from the start. This change will arise from a number of distinct sources:

- The world in which the system is to operate is ever-changing. What the user needs to be able to do, and consequently, what he wants the system to do for him, will change - perhaps slowly, perhaps rapidly.
- The technologies available for the system to exploit will change (for the better) and what was previously impossible/impractical will become feasible.
- The user's perception of what he wants of the system will change from the very moment it is in use, even if the rest of the world were static. Only when the system is used for real will users identify additional or different features they desire.

The first two points can be addressed by actively exploring how the possible problems (the first point) and the possible solutions (the second point) might change in the future. This is discussed further below.

The last of these points is almost a separate issue. It is what makes systems developments based on paper specifications and paper interim products (design specifications, etc) inherently weak. It is best addressed by a development in which end-user involvement is as deep as possible throughout; there is great emphasis on increments and iteration; and there is maximum flexibility to change direction. In the software world, disciplined RAD (Rapid Application Development) methods such as DSDM (Dynamic System Development Method)[2] provide such a development technique.

Predicting Change. We have a number of sources that can help us identify changes in both the problem and solution domains, eg:

- The commercial world (which is often only too ready to promote "futureware"!)
- Research programmes, both general and defence-oriented
- Military intelligence

COTS items are likely to be especially suitable for this “crystal ball gazing” since their developers and suppliers usually have a well-defined forward plan for future products.

Some changes are in fact very predictable, especially in the solution domain. We know that processors will become more powerful, communication bandwidth will increase, mobile 'phone technology will become ever-more sophisticated (eg internet access), and so on.

Of course, the solution and problem domains are by no means disjoint. One impact of COTS is that potential foes are likely to enjoy essentially the same access to COTS items as we are. Indeed, it may be that they are much more agile in exploiting them than some national defence forces. Hence a potential solution may also be a potential problem.

[1] A Viking king who commanded the waves to stop coming up the beach (although in fact he did not actually believe he could control the waves, but wanted to show that mortals are powerless over some things).

[2] See www.dsdm.org

It is also important to consider less obviously predictable changes. By definition, these are more difficult to identify, but "what if" scenarios based on the more outlandish of the concepts pursued in research environments should not be ignored.

The usual combination of "likelihood of happening" and "impact" can help guide the choice of possible changes for further consideration.

Managing Change. Combating obsolescence requires relevant possible changes to be studied, so as to influence the system as a whole (its design, concept of use, etc) throughout its life.

For example, we can consider a command and control system in which data exchange bandwidths are much greater than is currently achievable, but which might reasonably be expected to be attainable just a few years after initial delivery of the system.

It might be that totally new opportunities for the way in which the system is used are opened up by this increase in capability. Perhaps the user could have more or better (eg more accurate) information available in the same time, perhaps he could just have the same data but much more quickly, or perhaps more people could have the same data. Any of these alternatives might suggest a different way in which the system might be used.

Other examples might be: i) future technology makes equipment so much more portable that each soldier can carry what now goes in a vehicle; ii) many more users need to be connected simultaneously; iii) the enemy develops a more powerful jamming capability. All these could make the current system obsolete, even if obsolescence in the sense of component availability is not an issue at all.

At any point in time, therefore, we have the following entities to consider:

1. The problem space[3] - the environment in which the system is to be used and from which user needs emerge. This is many-faceted, covering the full spectrum from physical terrain and physical platforms to knowledge and tactics of all participants other than the system operator.
2. The solution space - the physical system itself and the way in which it is used:

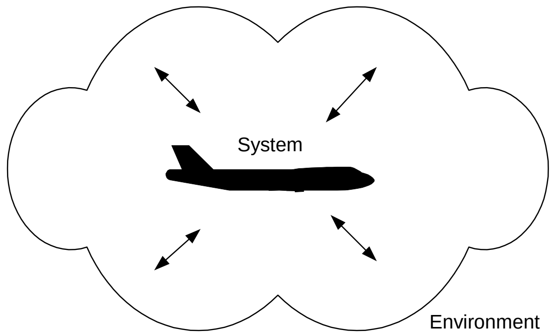

Figure 1 The System in its Environment

Furthermore, by looking ahead, we have two or more such pairs:

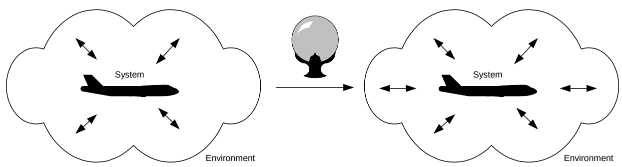

Figure 2 The System Now and in the Future

The future view represents the anticipated system and its use. This vision of how the system will be required to evolve forms a key input into how it is designed now. Knowing that a system and/or the way it is used will change in a particular way in the future is a crucial piece of data to inform the system design.

Very broadly, we have a number of inter-related aspects to consider:

1. The user needs within an environment now
2. The future user needs within a future environment
3. The system and its use that meets the needs now
4. The future system and it future use

There are a number of levels of abstraction at which we can consider all these items: the problem and solution domains, the user needs and the system that meets them, and the system's requirements and design. We can also consider "the system" to be the physical system, the users, the method of use, etc. These various aspects are related as shown below:

[3] Note that here the "problem space" is not the collection of problems, but the context in which the problem exists and in which the system aims to provide a solution.

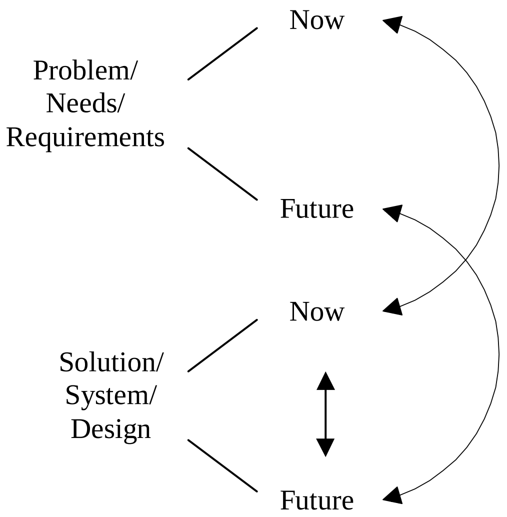

Figure 3 Solution and Problem Interactions

The design of the system that is produced now is, of course, driven by the requirements, but in addition - especially in a COTS-based system - the requirements are tempered by what is possible in the design and trade-off is needed. Similarly, when considering future needs and system possibilities, the same relationship between requirements and design exists.

Also, the system that we design for the future has an influence on how we design for the present, so that the transition to the new system is facilitated. On the other hand, we need to consider the current design when deriving the future system, for the same reasons.

Of course, it may be that in considering the future we decide that the gap between the current system and the one that is appropriate for the future is so great that a continuous transition is not appropriate and a better option is to develop a system with a short life and completely replace it in the future.

A number of forward-looking horizons may be appropriate. For example, we might look at now, 5 years' time and 10 years' time and consider how the problem and solution might appear at each stage, and how to accommodate this. Obviously, the further into the future the view is taken, the more approximate are likely to be the various items of information.

In terms of the system engineering artefacts that must be created, managed, etc, this approach introduces a number of new items, in addition to all the classic ones that exist when no forward look is taken:

- The requirements for the future system
- The design for the future system
- A change plan for the transition from the current system to the future

The change plan sets the way forward for the system based on the predicted changes in technology etc (the solution space) and needs (the problem space). It may include interim stages along the path from the current to the future positions, depending on how large the current-future gap is.

As with classic "point"[4] system design, traceability between the design drivers and design features is important. Thus, for example, it is crucial to maintain traceability from a particular design aspect back to its justifying element of the change plan.

The forward-looking artefacts discussed here clearly need to be maintained as time passes. Periodically, the assessment of future needs, future solution options (eg new technological capabilities) and the design for the future system itself can be revisited and updated as appropriate, resulting in a revised change plan.

Thus while the system itself may be essentially static (ignoring routine fixes and minor enhancements), the future system – that is, the envisaged actual system, the way it is used, etc – may be "upgraded" more frequently.

The following diagram shows successive versions of the physical and future system with asynchronous upgrades. The future system bars show the lifetime of various versions of the *prediction*, not of the actual system. Thus, for example, version 3 of the future system which is current when the physical system is upgraded to version 2 may predict the position some years after version 2 comes into service. Version 3 of the future system – ie predicted future needs and system design – will influence version 2 of the physical system via the relevant change plan, but it is not necessarily true that the introduction of a modified system will change the prediction for the future, so the future system is not affected. What must be upgraded, of course, is the change plan.

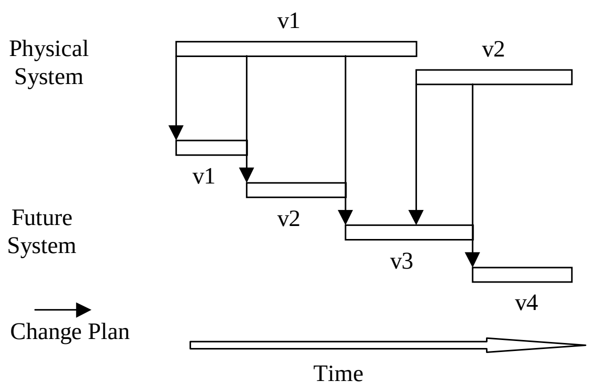

Figure 4 Physical and Future Systems

[4] ie that addresses the problem and solution at just one point, not across a now-future range

Note that the change plan is updated whenever either the physical or future system is modified.

Since in practice the physical system is unlikely to be totally static, the work on revising the future system can inform and influence minor changes to it.

The requirements and design for the future system and the change plan are products of an obsolescence management activity, controlled by an obsolescence management plan. Related activities to be covered by the plan include identifying the parts of the system – or problem domain – that are likely to be affected by obsolescence and deciding at what frequency to produce new versions of the future system.

Simulation. Simulation of various kinds (including here, for convenience, modelling) is a well-established tool to assist in the development of defence systems. Analysis activities, such as support for balance of investment decisions, rely heavily on simulation to explore the cost-effectiveness of various system options. More generally, simulation-based acquisition is achieving growing acceptance and importance, allowing a whole range of alternatives to be explored during system design and to be validated during system integration and acceptance. However, simulation specifically to address obsolescence issues appears to be relatively rare.

Simulations that represent the system as it is currently designed, and of the environment with which it interacts, are required to assist the understanding of interfaces, performance, emergent properties, etc during design, and to aid integration and validation.

In addition, simulation is an obvious way (indeed, probably the only way) to explore the system and its environment in the future.

For designing today's system, fine-grain, high fidelity simulations may be needed, but the more one is looking into the future, the more likely it is that coarse-grain, low fidelity simulations will be appropriate. Since such simulations are generally quicker and cheaper to develop, this has the advantage of making it more feasible to explore a number of different variants of the predictions.

"Broad brush" simulations at a relatively high level of abstraction may well be used during the initial stages of system development anyway (eg in exploring user needs and in identifying options). With suitable forethought the same simulations may be exploitable for looking at future systems, for example through parameterisation.

Systems Engineering Impact. The approach described here introduces a number of new systems engineering artefacts:

- Obsolescence management plan
- Change plan
- Future system requirements
- Future system design
- Future simulations (system and environment)

All these require to be seen as part of the core set of systems engineering artefacts for the system and to be managed appropriately.

In addition, we can see how this approach affects the systems engineering activities. One obvious impact is that when the current system changes in some way, all these new artefacts must be examined and refined as appropriate, with configuration management applied. Traceability is also a key concern.

The new (draft) ISO systems engineering standard, ISO15288, identifies a number of processes, as shown in Figure 5.

It is clear that obsolescence management has an impact on most of these to a greater or lesser extent and in one way or another. Considering future requirements and designs as well as current ones inevitably introduces additional work and complexity, which affects processes across the board. However, the major impact is on Stakeholder Needs Definition, Requirements Analysis, Architectural Design and Implementation.

Stakeholder Needs Definition is concerned with understanding what the system must do, and obsolescence management extends this to considering future needs as well as current/short-term ones. The future requirements will be identified here and this activity will require appropriate simulations of the future problem space.

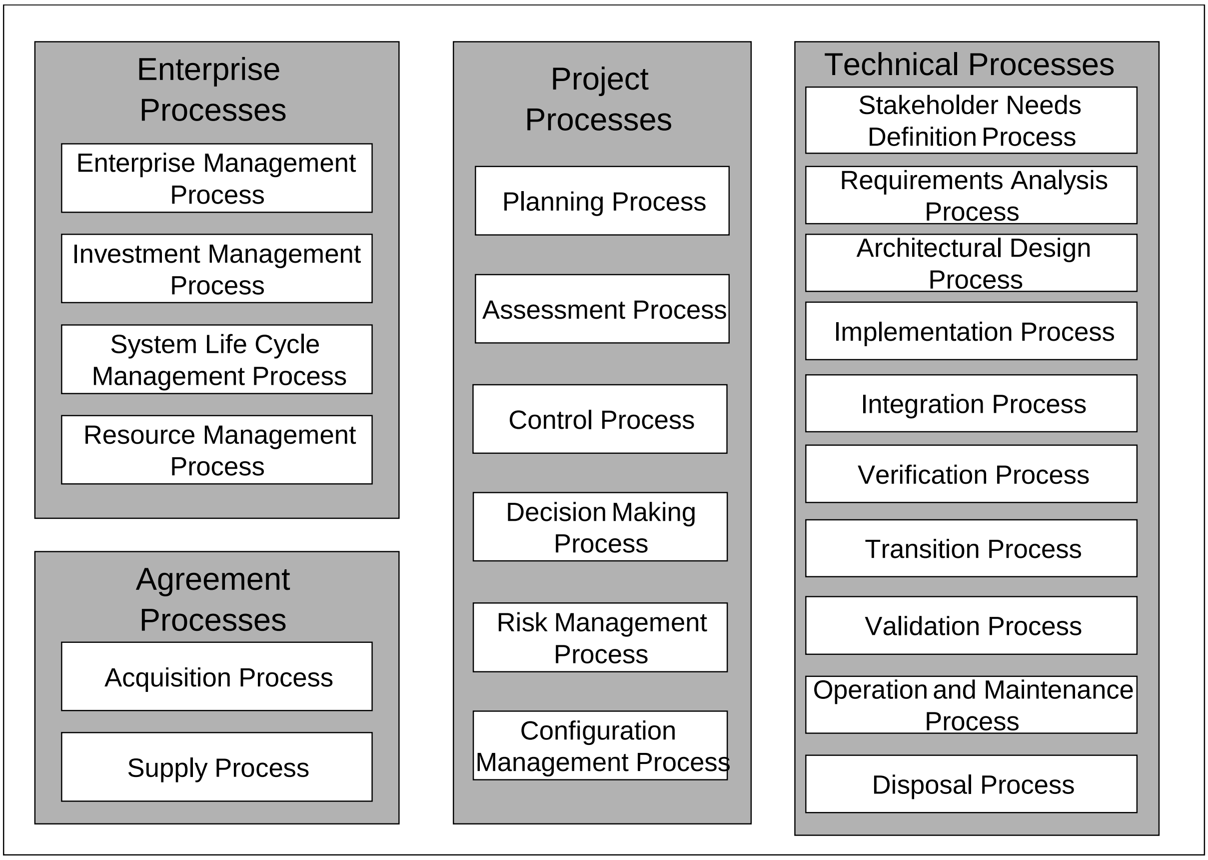

Figure 5 – ISO15288 Systems Engineering Processes

Requirements Analysis leads to a system requirement based on the stakeholder needs. In practice, there is often a rather hazy line between requirements analysis and design since often a particular model (or several models) of how the system might look tends to emerge at this stage. Hence the impact of future solutions may well need to be considered here, as well, of course, as considering future needs in addition to current ones.

Architectural Design is obviously very much affected by the need to consider what solutions might exist in the future to cater for the identified future requirements. Architectural Design involves trade-off decisions between various design options, and this is a key activity when deciding how the current design should be influenced by obsolescence management issues. It is here that the future design is derived, using appropriate simulations. The change plan will also be produced here.

Implementation is concerned with taking the output of the Architectural Design process as a set of requirements for lower level sub-systems and repeating the analysis and design activities. In practice, for large systems such as an aircraft, it may well be that it is at this stage that many obsolescence issues are first studied in depth. However, it is important that their impact is reflected upwards. For example, it may be that during the Implementation activity, it is decided that a particular box will be half its current size and weight in five years' time. The future aircraft design must reflect this opportunity.

The ISO standard is clear that the various processes are not necessarily executed sequentially. Even ignoring obsolescence, iteration between the four processes discussed here is vital, especially when COTS is being exploited. The approach described here can be seen as introducing a parallel iteration between requirements and design for the future system, and between the current and future systems, as shown in Figure 6.

It is interesting in passing to note that while the ISO standard certainly does not preclude obsolescence management as described here, it makes no explicit mention of catering for it. Its focus is on maintaining the system as first delivered and reacting to new needs as they arise, rather than predicting new needs and solutions. It is reactive rather than proactive.

Procurement Impact. A very obvious impact of this approach is that it involves extra effort, cost and time, compared with simply ignoring obsolescence. This is a major issue since it seems

all too common that, for a variety of reasons, investment in “up front” activities for systems is difficult to obtain.

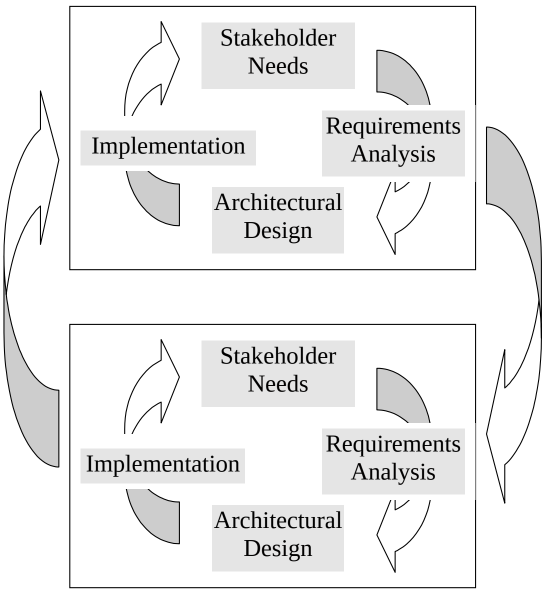

Figure 6 Iteration Within and Between Systems

The amount of effort that it is appropriate to put into obsolescence management clearly depends on the risk of obsolescence and its expected impact. In this way, obsolescence is no different from any other factor influencing the system. The overall risk management for the system should include assessing obsolescence risks and deciding upon the appropriate degree of forward planning. However, it is clear that the necessary effort could well be significant.

Since obsolescence arises from the problem domain as well as the solution domain, this is obviously an issue that should be considered by the user/procurer at a very early stage. It is not driven solely by aspects of equipment obsolescence and cannot be considered as something to be left to the system supplier alone. The approach adopted may have a major impact on the system’s through-life cost profile.

Neither is it a matter simply of cost and possibly timescales. It may be that analysis shows that to address an anticipated obsolescence problem, the initial system should have characteristics that would be considered sub-optimal if the system were not to be upgraded. Thus initial users might be asked to accept sub-optimal performance now to provide a better (or perhaps simply cheaper) system later – based on predictions of future needs and solutions. There are obviously very complex trade-offs and decisions to be made!

Conclusion. Obsolescence in systems has many causes, but ultimately is due to change in the problem space and/or the solution space. By attempting to understand the nature of this change for any given system, we can facilitate adapting to it. This requires the future system requirements and design to be derived, and a change plan to transition from the current to future system to be produced. COTS elements may be particularly amenable to this kind of forward looking since they often have a predictable development path.

Obsolescence must be a major element of the system’s risk management and this will decide the degree of investment that is appropriate. There may also be major issues involved in trading off immediate functionality to facilitate future changes. Procurer commitment to this approach is therefore vital.

Simulation will play a major role, especially in assessing future needs and solutions. These simulations and the various other artefacts (future design, etc) become key systems engineering products and must be managed accordingly. The "whole" system becomes the traditional physical system, its design, etc plus these other items.

It is clear that this approach is non-trivial. However, to at least ask for all systems the question “how much of this should we do?” seems to be vital in reducing the impact of obsolescence.

Adopting New Software Development Techniques to Reduce Obsolescence

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Abstract:

This paper reports on the advanced techniques employed in the specification of software requirements and the subsequent software development for an E-Scan demonstrator Radar Data Processor. This involves the Rapid Object-oriented Process for Embedded Systems (ROPES) [1], UML syntax, object-oriented design, and automatic code generation and test.
The COTS technology reported is in terms of commercially available state of the art method and tool support for the software analysis and design. The resulting software product contains a significant proportion of COTS code resulting from the code-generation. We are also using automation in development of our MMI, a COTS GUI-builder, and COTS hardware and operating system.
In this paper we also report on the object-oriented method, using the ROPES process, together with information about how in practice we are implementing the theory. We present the structure of the software and how it relates to the application under development.

With these techniques there are significant reductions in obsolescence due to:

- customer visibility and understanding of the product under procurement, making clear the advantages and limitations of what will be produced,
- development of a coherent, consistent and maintainable system specification,
- use of use an industry-standard model notation (UML) to capture the analysis and design, enabling portability of the design to other tools and products,
- flexibility in catering for evolving requirements,
- development of testable requirements, enabling original functionality to be re-checked after addition of enhancements,
- techniques for enabling the re-use or replacement of modules with defined interfaces,
- easy and maintainable connections between specification and implementation,
- high initial quality and low rework costs.

This paper will be of benefit to those just embarking on system and software development, or considering updating processes in a legacy project. It is also applicable to those just embarking on choice of tools and methods for initiating programmes as well as for early feasibility studies.

Keywords: System Specification, Requirements Analysis, Real-time, UML, Object-oriented, Analysis, Design, Modelling, Code-generation

1 Introduction

The E-Scan radar project is aimed at producing a flying demonstrator of an electronically-scanned phased-array antenna. It will be fully capable of tracking targets and will provide some advanced features such as adaptive beamforming, but will not include the full range of functionality of a system such as the Captor Radar integrated with the Eurofighter Typhoon weapon system.

The Trials Monitor Computer (TMC) is the main processor in the radar and is responsible for the signal and data processing, as well as controlling the activities of other subsystems such as the antenna and the receiver/exciter. The TMC consists of two main areas:

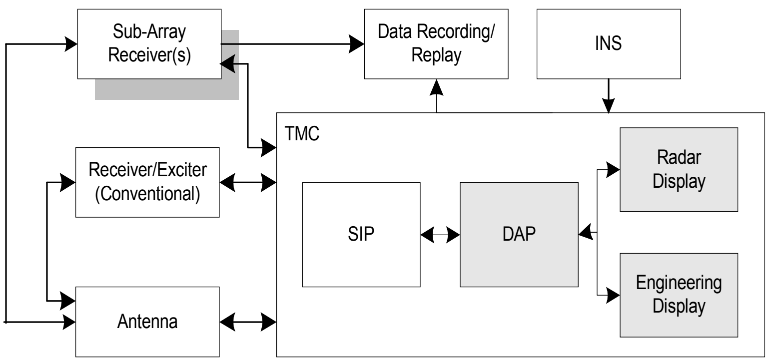

Figure 1

Paper presented at the RTO SCI Symposium on "Strategies to Mitigate Obsolescence in Defense Systems Using Commercial Components", held in Budapest, Hungary, 23-25 October 2000, and published in RTO MP-072.

the Signal Processor (SIP) is largely for handling the flow of digital data from the receiver and processing it continuously to obtain events relating to target detections; the Data Processor (DAP) is event-based, creates tracks of targets from the detections and manages the distribution of RF power radiated, and has an MMI for controlling other functions.

Both SIP and DAP use predominantly COTS hardware, with commercial operating systems and development tools.

This paper relates to the DAP.

2 Technical Details

2.1 State of the Art Software Tools

At the outset, the decision was made to invest in technology to reduce the cost and timescales of software development. This approach is key to making a successful demonstrator in a short period.

The tools have to provide analysis and design support, starting from requirements with a clear path through the design to automatic generation of code from the design (not just code frames). To validate the design, simulation is essential and the testing support must enable verification of the generated system behaviour against that defined in the requirements.

From the handful of tools that met our basic requirements, we chose the I-Logix Rhapsody tool, which provides for full UML analysis and design, code generation and automatic verification against scenarios.

Our core tool set consists of Rhapsody (analysis, design, simulation, verification), DOORS (requirements tracking) and ClearCase (configuration management). Although from different manufacturers, these tools provide useful integration and have been found to work well together. Supporting these are the usual set of C++ compilers, host support (the Wind River RTOS VxWorks) and other productivity enhancements (See Figure 2).

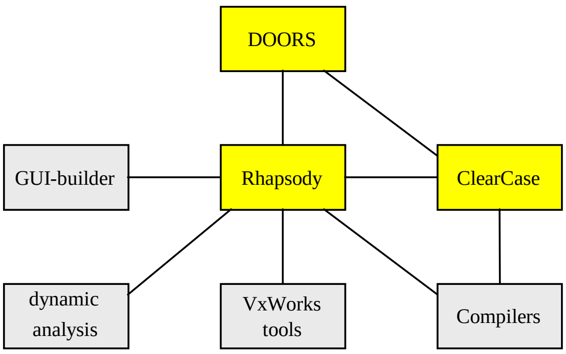

Figure 2

From an obsolescence perspective the capability of the Rhapsody tool to select a target environment is of particular importance. As target platforms become obsolete the tool has a number of platforms that can be selected and the code regenerated for that particular environment. The tool vendor is increasing the number of target platforms supported as market forces dictate.

An early decision to purchase consultancy and training on both tools and methods has proved to be very fruitful and well worth the outlay.

2.2 Using UML

The UML is a notation that has evolved from Software Development. Some of the tools, such as Use Case and Sequence Diagrams are specifically aimed at creating a realistic model of what the customer wants.

Previously, the specification of requirements have been expressed as "Victorian novel" text – often disjointedly spread across a number of documents – combined with a collection of algorithms and little consultation with the software engineers responsible for implementation.

This has often been followed by what is described as the "over the wall" approach where the requirements are passed to the software engineers and the systems engineers move onto something else. Large amounts of software development effort is then spent rewriting the contents of the requirements documents into a Software Requirements Specification (SRS). This process is illustrated in figure 3.

The traditional approach leads to a number of problems:

1. Generation of the requirements is difficult to manage.
2. Traceability to, and Verification of, the requirements is difficult to achieve.
3. Maintenance of the requirements is expensive.
4. Software is difficult to develop.
5. Changes in requirements (which are accepted as inevitable) are difficult to implement.

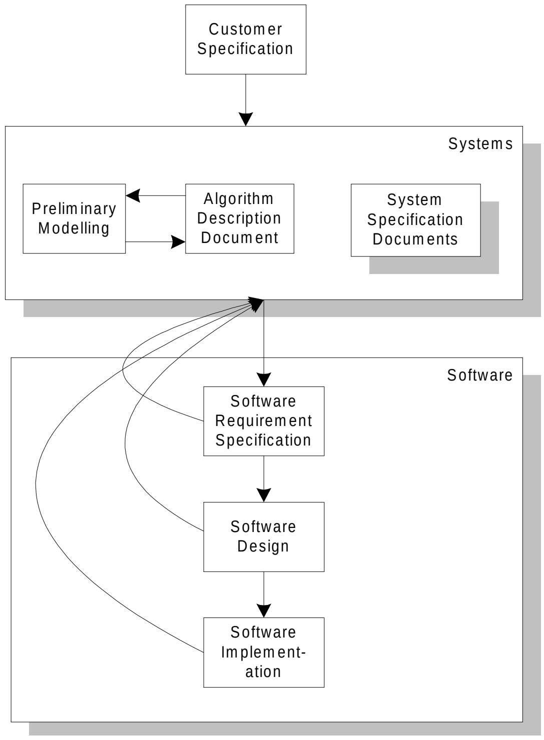

Figure 3

The approach we have adopted for the DAP is to have an integrated systems-software team (see figure 4) and a closely coupled SRS/ACD pair (see figure 5). This approach is detailed below

Requirements Analysis (from the ROPES perspective) is performed using Use Cases, Sequence Diagrams and Statecharts. The Requirements Analysis results in a functional decomposition of the DAP, the details of which are captured in the Software Requirements Specification (SRS). The Use Case descriptions give the functional details of the system in a textual manner, that will be utilised later in identifying objects, with the sequence diagrams defining the Use Case behaviour in a dynamic manner.

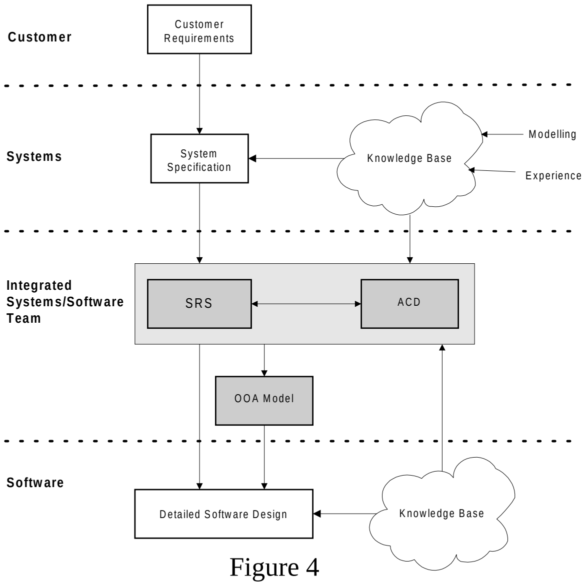

Figure 4

Algorithmic Definition is carried out based on this functional decomposition of the system, which is agreed early in the project lifecycle by the integrated systems-software team. The algorithms are described using Activity Diagrams to show the blocks and flow of algorithmic activity with references to mathematical formulae and textual descriptions as appropriate. This detail is captured in an Algorithm Control Document, which supplements the SRS.

By using the same functional decomposition for both documents, it becomes easier for the software team to understand which algorithms are required to implement a particular area of functionality (i.e. a use case).

The development of the SRS and the ACD are iterative in nature and can allow details of algorithmic implementation to be fleshed out much later in the lifecycle than would normally be the case. One of the benefits to this approach is early introduction of software engineering effort to the process which removes the lengthy delay whilst algorithms are "fully" defined by systems engineers before software development starts.

Links between the SRS and ACD enable the two documents to give a detailed and co-ordinated description of the System. Using hypertext links, an engineer or customer can navigate around the requirements with ease. Both the SRS and ACD are embedded in the DOORS Requirements Traceability tool.

With the creation of a closely coupled SRS/ACD pair a detailed definition of the system exists that can be well understood by those using it. This is the first step to ease of maintenance and the resulting reduction in overhead costs. Generally, maintenance of systems documentation (inevitable in light of changing requirements) is complicated by a poorly defined set of requirements that are scattered across a number of documents that have little or no real relationship. By ensuring that the Specification is easily understandable (using UML) and well laid out (and thus easily navigable) the impact of change can be quickly assessed and is less onerous to implement.

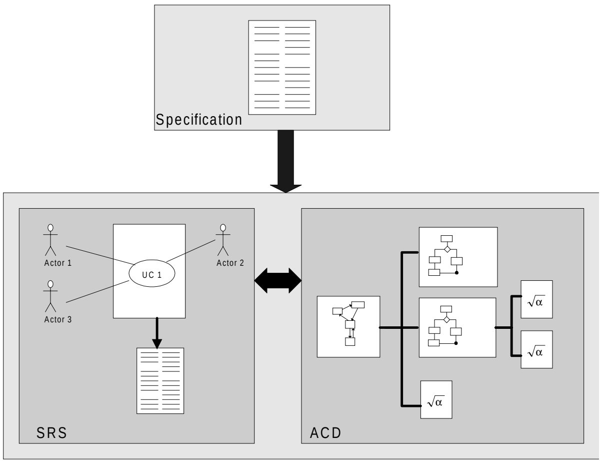

Figure 5

2.3 Systems-Software Integrated Teams

Experience has shown that unless the systems engineer understands the process by which their specification (itself another interpretation of the customer requirements) is implemented the systems-software review process is prone to failure. (Sometimes the systems-software relationship goes the same way.)

With the use of a common language of understanding that is intuitive in its usage these two problems can be alleviated. The fact that Use Case, Sequence Diagrams and Activity Diagrams are simple concepts to understand, powerful in their capability for representing complex requirements and are now widely accepted as a way of describing requirements means that the Software Engineers, who invariably pioneer these new methods, can achieve "buy-in" from the systems engineers.

For this relationship to be successful, it is essential that the systems engineering team are given the appropriate training in the development methodology and sufficient time to review the software work products – particularly the Object Analysis (both structural and behavioural).

On the DAP, systems engineers receive the same training in software methodology and tools as the

software engineers. A core team is formed which allows very close inter-working to take place on a level playing field. This enables the software engineers to bring their experience into the development of the system specification whilst allowing the systems engineers a greater understanding of, and input to, the software development process in the subsequent phases of the lifecycle.

In particular, the integrated team work together to create the software object analysis model. This co-operation helps the software team to understand the requirements and means the systems team will understand how the software will implement the requirements. During the creation of this model, the integrated team can ensure, at an early stage, that the software will implement the requirements and algorithms stated in the SRS and ACD.

2.4 Flexibility with Evolving Requirements

As stated, the DAP is being developed using the ROPES process. This is an iterative/incremental means of software development using the Spiral Lifecycle.

Use Case analysis gives a functional decomposition of the system. In our application each Use Case has been identified as an “Iterative Prototype”.

These prototypes are taken through the full software lifecycle to produce working software. This gives a great deal of scope for risk reduction in the early stages of a programme by allowing working code to be developed for a target platform. The choice of which prototypes should be developed first is based on risk impact assessment.

The additional benefit is that the prototype is re-useable, in so much as it is a building block to be used in the incremental development of the application.

By careful consideration, based on risk reduction and introduction of required (phased) functionality, the application is developed incrementally by the integration of the prototypes.

By adopting this development process there are two main areas of benefit in respect of flexibility.

The algorithmic development can continue during the software development process for agreed areas of functionality within the system (i.e. Use Cases that may be implemented later in the programme). The Use Cases and Scenarios give the functional structure, or framework, of the system under development at an early stage. This allows the OO development to progress to the detailed design phase before the algorithms must be completed.

In developing functional prototypes and quickly reaching the stage where executable software is running on a target (much earlier than in traditional developments), problems with requirements can be fed-back quickly and avoiding action taken. The prototype may be re-iterated and re-incorporated in the application to include the changed requirement.

2.5 Requirements Testability

Although the combination of Use Cases and Sequence Diagrams gives a powerful means of specifying the requirements there is an additional benefit to the creation of Sequence Diagrams. The use of Sequence Diagrams implicitly forces engineers to address the issue of testing the functionality being defined. This is as applicable for lower level integration test (for sub-system use cases) as it is for high-level system acceptance testing (system use cases).

On the DAP we use the Rhapsody CASE tool to carry out automated Sequence Diagram comparison. That is, the Sequence diagrams specified can be compared with those generated by the actual model created to fulfil the requirements.

2.6 Connecting Requirements through to Design Models

The analysis of requirements is carried out by first of all defining the Use Cases (i.e. the particular areas of functionality) as shown in figure 6. The Use Cases are initially just headlines, but are rapidly filled-out with scenarios: there will typically be a number of Sequence Diagrams for each use case, showing the functionality in specific situations (see figure 7).

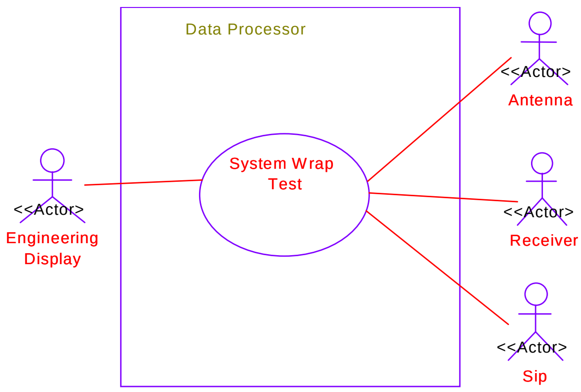

Figure 6-a

System Wrap Test

GOAL/PURPOSE:
Perform the Radar system wraparound communication BIT test.

TRIGGER EVENT: do Radar Wraparound test request from Engineering Display operator

PRECONDITIONS: The CAR radar is in a 'Standby' or Operative State.

POSTCONDITION:
Success End -'Wraparound Test Ok' message is indicated on the Engineering Display.
Failed End - Test failed or timeout. 'Wraparound Test Fail' message and the cause of failure shall be indicated on the Engineering Display.

MAIN SUCCESS SCENARIO
See Message sequence diagram 'MSC_Sys_Wrap'

EXTENSIONS
tbd

EXCEPTIONS
1.No response from any LRIs within TBD milli seconds , Initial policy is to abort operation and report a fault . In the future a recovery sequence (soft reset LRI and retry a max of 2 times) may be implemented.

PERFORMANCE (Quality of service)
Priority: Low. Any radar activity in progress should be allowed to goto completion.
Performance : Test done within 100 millisecond.
Frequency: Periodic - execute during a Resource Frame BIT slot (0.5 Hz)
Episodic - execute Wraparound Bit test on operator request

Figure 6-b

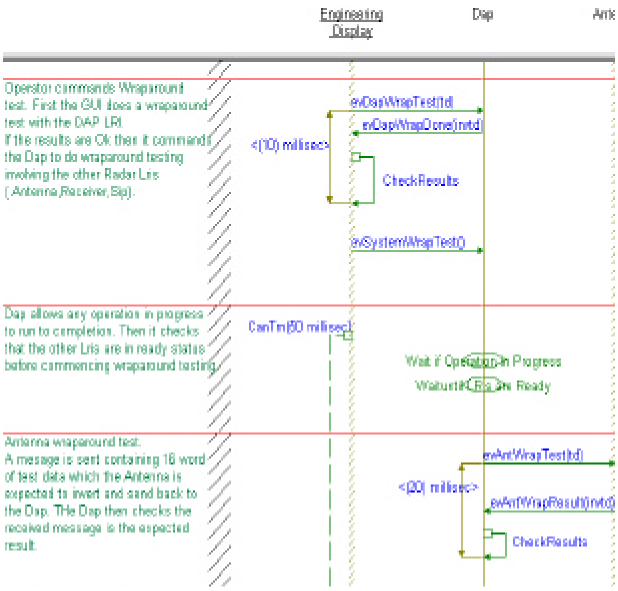

Figure 7

At this level, the analysis is very much in terms that a customer would understand – we are in the favourable position of being both pseudo-customer (writing requirements on behalf of the actual customer) and contractor (implementing those requirements), so we have been able to make sure that the analysis correctly echoes the requirements.

A key advantage is that, because the Use Cases and Sequence Diagrams are captured in the Rhapsody tool (subsequently used for detailed design) and linked back to source requirements in DOORS, requirements are traceable to the implementation.

2.7 Moving From Functionality to Objects: Domains and Subsystems

The methodology used on this project is Rapid Object-Oriented Process for Embedded Systems (ROPES), which brings together a number of the best practice lines of thought, specialised for real-time applications.

The first stage in this is to define preliminary “subsystems”, which are in effect collections of functionality. Each use case is placed into a subsystem – the use cases are decomposed to such a level as to ensure that each use case is in only one subsystem, though the subsystems will often contain more than one use case.

In figure 8, “Radar Control”, “Burst Control” and “Tracker” are the subsystems within the “DAP”.

The subsystems and their identified artefacts are defined as the “Physical Model”. This is captured in Rhapsody by a Physical package (shown in Fig. 11).

The often-difficult borderline between function-based specification and object-based implementation is encountered at this point: the implementation of the use cases is by domain classes instantiated in the subsystems.

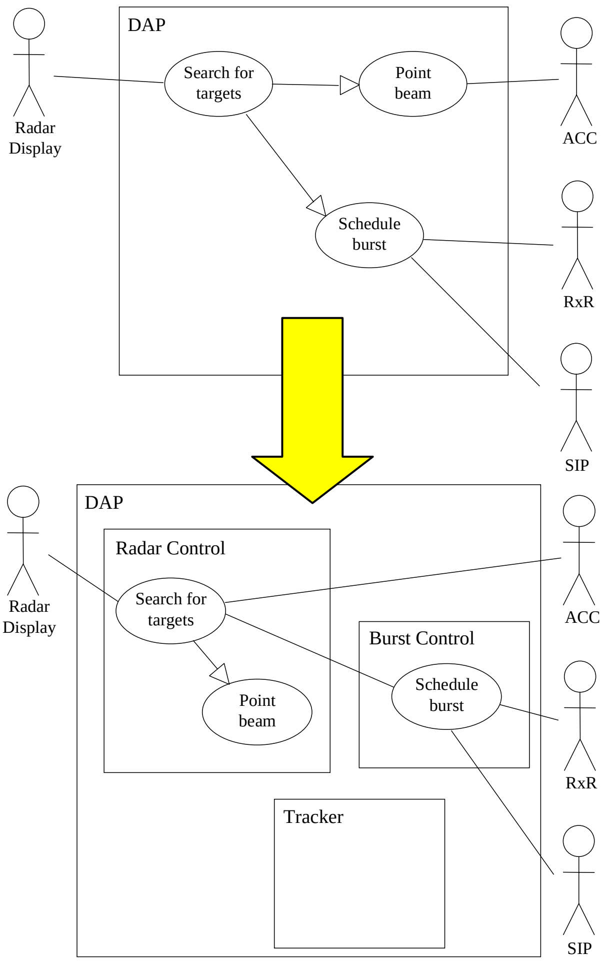

Figure 8

Subject Matter Separation, one of the useful aspects of the Shlaer-Mellor methodology has been imported into ROPES, in the form of domains. Within a domain are collected all the objects that relate to a particular subject matter (e.g. I/O, alarms, tracking). These are

an orthogonal set to the subsystems: all objects are in fact defined in domains, but are "used" in the subsystems. The collection of domains identified is referred to as the "Logical Model". This is captured in Rhapsody by a Logical package (shown in Fig. 11).

A domain diagram (figure 9) shows the inter-relationships between the domains:

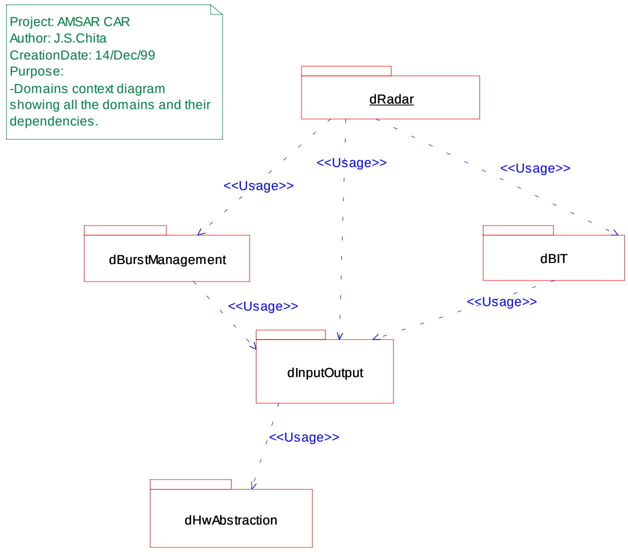

Figure 9

Although it would in principle be possible to follow the Shlaer-Mellor project organisation model and have domain specialists, we have chosen to avoid the potential for boredom in team members by dividing work by subsystem and use-case rather than domains, though we retain an element of domain-ownership to ensure consistency.

2.8 From Analysis to Design

The dilemma encountered with elaborational methods is that one may lose sight of the analysis after adding design information. The high level objects are created only in order that the use cases and their sequence charts may be defined and do not take account of whatever is found necessary for the detailed design.

One solution that has been proposed is to keep two models, the original analysis model and the design model (as elaborated). The difficulty with this is keeping the two models synchronised.

The alternative is to continue with a single model thus reducing analysis/design consistency issues. If one utilises the idea from ROPES that several "views" of the model can exist then one can show purely analysis views from which the design views are subsequently created.

2.9 Implementing Distribution

Shows how distribution is implemented when subsystems are located on separate processors linked via an Ethernet bus. Normally in a single processor system the 2 subsystem communicate with each via 2 associations links using asynchronous events:

1) MessageRouterController->iEngDisplay.
2) EngDisplayController->iDapCommand.

These associations for the distributed processor are then realised using a combination of 2 patterns (figure 10):

1) The Proxy pattern provides location transparency.
2) Forwarder – Receiver implements the interprocessor communication between the 2 subsystems.

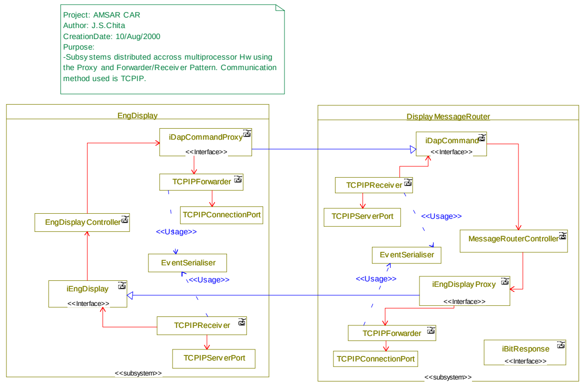

Figure 10

2.10 Units of Re-use

To achieve reduction in obsolescence, we must identify the specific units that are available to be re-used. The aim is to be able either to extract these units to be used in a new system, or to be able to replace units of the current system when changes in functionality are required.

We have identified two main areas of re-use:

a) Subsystem Re-Use, when exactly the same functionality (i.e. the same Use Cases) is required in a new system, or when the complete set of functionality is to be replaced with new functionality in the current system. The subsystem is a convenient unit of re-use as it instantiates all the classes it needs to operate (it can be seen rather as a PCB in hardware terms). When a subsystem is moved to another place, only its external interfaces need to be observed and attached into its new surroundings. This is done in practice by setting up relationships to defined *interface classes* for inputs to the subsystem and initialising the relationships from within the systems for its outputs. Both the identity of the interface class and the initialisation of output relationships are available as public operations on the subsystem.

b) Domain Re-Use, when classes in a domain, originally designed to implement a different set of Use Cases, can be re-used to create a new Subsystem. The domain classes can be seen as a

"toolbox" available to implementers of Use Cases, who are encouraged by publication of the domain services to pick classes from there rather than invent new classes. The benefits of the design patterns will automatically be achieved when the classes are used in a new Subsystem to fulfil the Use Cases of that Subsystem. This can be a more difficult level of re-use to achieve, because the implementer of a Use Case may identify slightly different requirements for the classes than those in the "toolbox" – but by careful management maximum use of existing classes, with inheritance to provide for small variations, can be achieved.

Because our development method clearly identifies both subsystems and domains in the artefacts generated, we have a head-start on achieving re-use.

3 Results

We have found the Rhapsody tool and the ROPES method to fit well into our environment. The requirements analysis has provided a sound baseline for the object oriented analysis and design, which is proceeding well. One additional benefit is that we can now provide to our partners in the project not just paper documentation of the design but also animated simulation prototypes.

By using a UML-based method we have also found it easy to bring new recently-graduating members into the team, making use of the training in object-oriented techniques that now commonly forms part of software engineering courses.

We have utilised the concepts of the Physical and Logical models to develop the software application [2]. The Physical model defines the system to be implemented, the logical model captures the domains which themselves contain the essential building blocks, or classes, of the system.

The System package contains the System Actors and the Subsystem architecture identified during Architectural design.

The Build package contains the incremental builds and is effectively the instantiation of the Physical model.

3.1 First Prototype

Our first prototype is based on a wrap-test of the system, which runs a communication check on simulations of the other subsystems. We took this prototype all the way from requirements through use cases to detailed design, implementation and test.

The following diagram shows a "browser" view of the system package structure. The domains have names starting with "d" and are captured in the Logical package, the subsystems "s" and are captured in the Physical package.

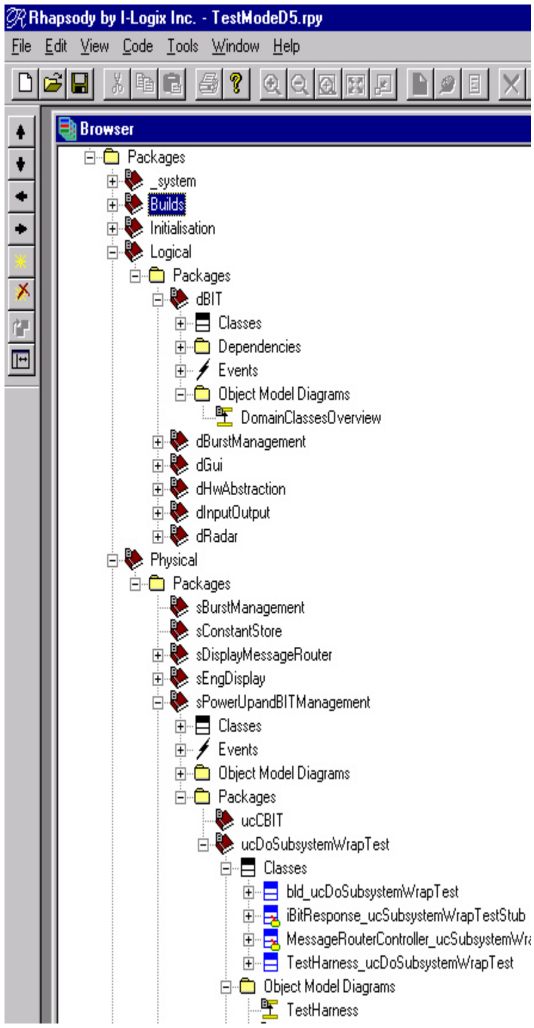

Figure 11

3.2 Physical Model: Object Model Diagram

The objects involved in a use case can be shown on an object model diagram for a particular subsystem:

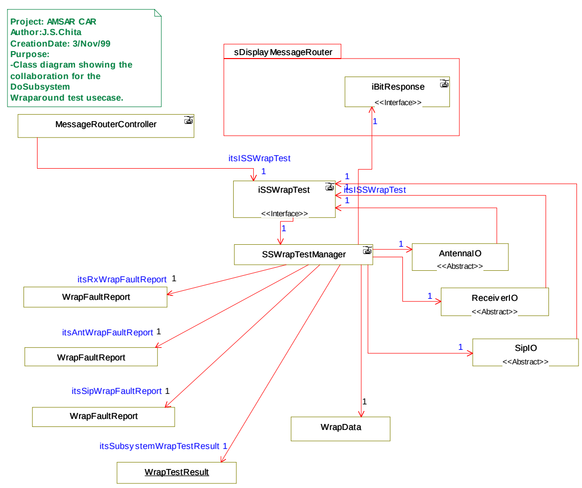

Figure 12

3.3 Logical Model: Active Class

The implementation of the behaviour of the active classes is generally shown in a state chart:

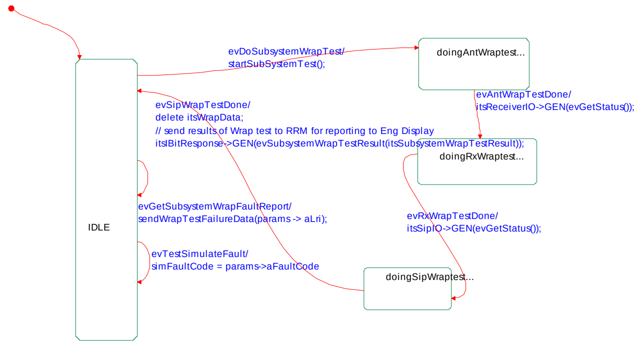

Figure 13

3.4 Build Model: Usecase Instantiation

Shows the classes used to build up the use case.

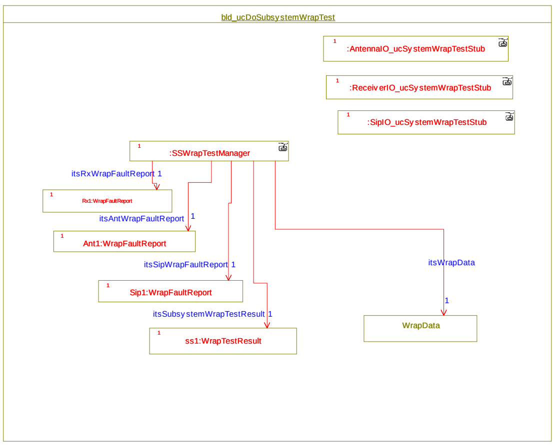

Figure 14

3.5 Build Model: Subsystem Instantiation

Shows the classes used to build up the sub-system.

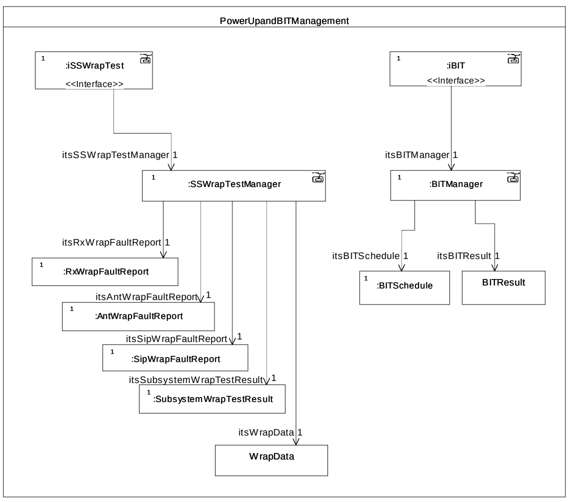

Figure 15

3.6 Build Model: System Instantiation

Shows the classes used to build up the DAP system for standalone testing on the PC development host.

Figure 16

The wrap-test has proved successful not only as confirmation of the tool and method choice, but also as the first real prototype that implements part of the functionality of the full system.

4 Conclusions

Software represents a large and increasing proportion of the costs of current systems. Current high software costs for almost every project indicate that this is an area where reduction of obsolescence and increase of re-use must be introduced if costs for future systems are to remain within limited budgets.

While the object-oriented approach provides a basic framework for encapsulating functionality to provide a theoretical possibility for re-use, it does not of itself provide the key advantage. Simple insertion of object-oriented analysis and design into a company's processes does not provide all the advantages that could be obtained, some companies finding little benefit.

To take full benefit from object-oriented techniques, a coherent method of capturing the requirements in a customer-visible way, analysing those requirements to provide the basis for the design, managing the key step from functionality to objects and building up functionality with prototypes must be used.

We are convinced that our use of the ROPES method with advanced tool support will enable us to build up software matching the requirements, to maintain that software as requirements evolve, and to re-use significant parts of the software in new systems having requirements in common.

5 References:

[1] Douglass, Bruce Powel, Doing Hard Time : Developing Real-time Systems with UML, Objects, Frameworks and Patterns, 1999, Addison-Wesley, ISBN 0-201-49837-5.

[2] Douglass, Bruce Powel, Effective Use Cases for Real-Time Design, Version 1.3.1

6 List of Acronyms

ACD	Algorithm Control Document
COTS	Commercial Off The Shelf
DOORS	A requirements traceability tool
GUI	Graphical User Interface
MMI	Man Machine Interface
ROPES	Rapid Object-oriented Process for Embedded Systems
SRS	Software Requirements Specification
TMC	Trials Monitor Computer
UML	Unified Modelling Language

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Software Radios
for Maximum Flexibility and Interoperability

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Abstract

The upcoming Software Radios will change the commercial as well as the military market of radio communications. Due to their programmability Software Radios offer an extreme flexibility falling into 3 main domains: Multirole, Multimode and Multiband operation. Multiband just means that the radio can cover the complete spectrum from HF to SHF, Multimode requests to cope with different air interfaces and Multirole addresses the question, which applications a software radio has to serve. Essential properties of a software radio architecture, particularly supporting the use of COTS components and mitigating parts obsolescence, are the strict decoupling of application software and platform hardware (forming APIs) together with a consequent modularization of the hardware. The decoupling allows hardware-independent development of the application software, whilst the hardware modularization supports a cyclic reengineering process in case components have to be replaced by new COTS parts. Savings in term of logistic and upgrades reduce the overall life-cycle costs by about 40 percent in comparison with conventional radios. In turn, these platforms are free to be scaled to manpack, airborne, naval or stationary deployment, simultaneously optimised for example in terms of power saving, size or flexibility, where the software layer guarantees interoperability among these radio families by common waveforms. An example of an existing military software radio is presented showing multiband, multimode and multirole features.

Introduction

In former days radios for military applications often have been supportable for 25 to 30 years. Components, once selected in the design process, have been available for many years and one could expect that there are suppliers for these components active on the market even after a long period of time. On the other hand waveforms and transmission methods in the military as well as in the civil world have been stable for years. The technical progress was low compared with today and military technology was regarded nearly always to be ahead of civil technology.

As we all know times have changed. Today components like microprocessors double their performance within a few years. As a consequence obsolete components tend to vanish from the market. But not only components are getting obsolete. Driven by civil communications technologies like GSM, TETRA, UMTS or Wireless LAN military people have to face the fact, that in many cases they do not have equipment comparable with civil equipment in performance any longer. The capabilities of military equipment are getting obsolete too. It has to be expected that this trend will speed up in the future.

The effects of this trend are that life cycle cost are increasing, lifetime is decreasing and there is a time lag of military technology compared with civil technology. On the other hand military logistics require equipment to be stable and to survive even if technology is setting the pace.

Means and concepts have to be found to fight these effects. One of these concepts is the Software Radio technology.

How can Software Radio Technology contribute to mitigate obsolescence and life cycle cost?

Paper presented at the RTO SCI Symposium on "Strategies to Mitigate Obsolescence in Defense Systems Using Commercial Components", held in Budapest, Hungary, 23-25 October 2000, and published in RTO MP-072.

The User’s Need

In times of decreasing military budgets the cost factor is one of the most important issues for the user. Life Cycle Cost is a suitable figure to express the overall cost for the user.

Life Cycle Costs consist mainly of

- Purchasing costs
- Maintenance support costs (including spare parts)
- Test equipment costs
- Transportation and handling costs
- Training costs
- Facilities costs
- Documentation costs

Life Cycle Cost shall be optimised in sum.

Changing boundary conditions like altered military strategies and tasks (e.g. peace keeping operations) finance flow or upcoming new waveforms require the possibility to update or upgrade the equipment. Update means to improve the equipment maintaining the same functionality, whilst upgrade means to increase the functionality e.g. by adding new waveforms, options or interfaces. It is highly desirable to perform update and upgrade by software download means only. Changing the hardware or software configuration calls badly for an efficient configuration management. The user needs to know the actual status of the hardware or software implemented.

In the past each waveform or transmission method had its own, dedicated equipment. The new global political context increases international operations like humanitarian aid, peace keeping and peace forcing tasks. Interoperability between different nations using different military waveforms will be mandatory in the future. Equipment must be able to be switched between different waveforms. Humanitarian aid requires also interoperation with civil authorities with their dedicated frequency bands and civil waveforms. This shall be performed without exchanging assets as far as possible.

Multiband, Multimode, Multirole

As for **multiband** operation, a Software Radio should cover a maximal frequency range starting from HF (about 1.5 MHz) up to several GHz because of various reasons: The increasing demand for information exchange and its involving broadband waveforms are facing sharply limited frequency resources and are shifting applications to higher currently not used frequency ranges. Secondly, each country has its individual frequency assignment scheme. Finally, ITU refarming procedures place civil, commercial communication in formerly military occupied frequencies. GSM or the security service system TETRA for example covers a broad range of frequencies. Therefore, multiband operation is of extremely importance to cope with mobility requirements across international borders.

Frontend modularity helps to extend frequency bands in the future. Experience shows that the broader the covered frequency band the more challenging it is to maintain performance over the whole band.

A software radio, however, must not place unrealistic demands on linearity, image rejection, dynamic range and interference reduction. From the current technology point of view some analog

Multiband	Multimode	Multirole
Multiple Frequency Bands	Multiple Air Interfaces	Multiple Applications
HF 1.5 - 30 MHz	Civil waveforms TETRA, GSM, UMTS, AM, FM, VDL ...	Radio Terminal, Relais, Base Station, Data Link, Civil, Military
VHF 30 - 174 MHz	Military waveforms FSK, HQ, SATURN, L11, L22, JTIDS ...	Handheld, Mobile, Airborne, Stationary
UHF 225 - 400 MHz	High data rate waveforms	Point to Point, Point to Multipoint, Broadcast
UHF + 400 - 2000 MHz	COMSEC/TRANSEC	Voice, data, video
TETRA bands	TDMA, FDMA, CDMA	Different Interfaces, Protocols, Rem. Control
Frontend modularity		
Colocation issues		
Pre**p**lanned **P**roduct **I**mpr.	**P**re**p**lanned **P**roduct **I**mpr.	**P**re**p**lanned **P**roduct **I**mpr.
PPPI	**PPPI**	**PPPI**

Figure 1: Multiband, Multimode, Multirole

pre-processing by mixing and filtering helps a lot to meet requirements in terms of power consumption, size and collocation performance.

Multimode operation requests the Software Radio to be compliant with various air interfaces. Throughout the civil world there exists a large number of different standards, e.g. GSM in Europe, IS-95 and AMPS in the US and there will be no convergence of wireless standards in the future due to political/commercial (see for UMTS) and technical reasons. Amplitude Modulation (AM), frequency modulation (FM) and frequency shift keying (FSK) are still widely used legacy waveforms. Digital modulation schemes like QPSK, GMSK and D8PSK are required by modern waveforms.
In the military area there are various NATO standards and proprietary waveforms in use. Often there is a requirement to switch from one waveform to another either due to tactical/operational or due to maintenance reasons (switch-in of a backup unit).

Multirole operation addresses the question, which applications a software radio has to serve. Besides the capability to handle voice, data and video transmission a Software Radio has to answer to different operational scenarios particularly placed by different roles. These operational scenarios influence the choice of line interfaces, line protocols and remote control concepts.

Combat Net Radio (CNR), Radio Access Point (RAP), Relay and Data Link are typical applications a military Software Radio must meet. It has to be scalable from handheld with stringent power consumption requirements over airborne equipment (optimised in size), manpack up to a base station with several communication lines in parallel. Besides typical hierarchical networks (between mobile and base) mobile radios should be able to establish links among themselves, like TETRA's direct mode. A Software Radio has to cope with lots of different access and network control schemes, introduced by advanced supplementary services (e.g. Access Priority, Dynamic Group Assignment, Late Entry, Remote Disable/Enable) or redundant, multi-hierarchy networks. That applies to fixed networks such as ISDN/PSTN, LAN, WAN and to moving networks on the air as well. A Software Radio should be able to establish point-to-point and point-to-multipoint links and to provide broadcast services. Consequently, there is a need to build radio families based on scalable platforms to meet the requirements in terms of size, weight power, functionality and performance.

The core feature across the multiband, multimode and multirole properties is Preplanned Product Improvement (PPPI). The design target is to foresee prerequisites for future extension and improvement of the radio. A vast majority of improvements can then be performed my sole means of software download.

Software Radio Architecture

One of the key elements of Software Radio Architecture is the strict separation of the applications (software) from the hardware platform by horizontal architecture layering. This principle, which is well known from PC technology, offers a well defined, hardware independent interface (API) to the software (see Figure 2).

Typically, the Software Radio Architecture is functionally partitioned into different modules interconnected by Radio Control Buses (RCBs).

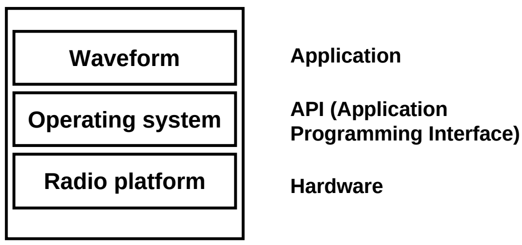

Figure 2: Separation of Applications from the Hardware Platform (Horizontal Approach)

Analog to the ISO/OSI-model we can distinguish between channel processing, modulation processing, bitstream processing and network processing (Figure 3).

Channel processing includes amplification, filtering on RF and IF level, RF switching, RF matching, mixing, AGC/ALC (automatic gain control/ automatic level control) etc. Processing is done on analog and digital levels.

Modulation processing (or waveform processing) is dealing with all kind of manipulation and managing of the signal like modulation and demodulation, equalisation, digitisation, symbol tracking.

The module **bitstream processing** performs operations on bit level. Those are e.g. forward error correction, interleaving and ciphering. In context with ciphering red/black separation has to be taken into account if necessary.

Network processing includes the Media Access Control (MAC) functionalities, routing, and network management.

The modules in Figure 3 show the horizontal layering as in Figure 1, separating hardware and software parts from each other. The software incarnated by DSPs and programmable FPGAs holds the control over the main operating parameters and offers an extreme flexibility with benefits in both commercial, security services and military applications. Moreover, due to well defined and standardised interfaces between the modules, which prepare some kind of "open architecture", modules can be simply plugged into or moved away from. As a result the radio platform is scalable to e.g. handheld, manpack or base station applications. This optimisation in terms of power saving, size or flexibility is of particular importance, since hardware components represent a bottleneck in terms of radio performance. The software driven hardware platform allows an easy implementation of advanced waveforms and functions.

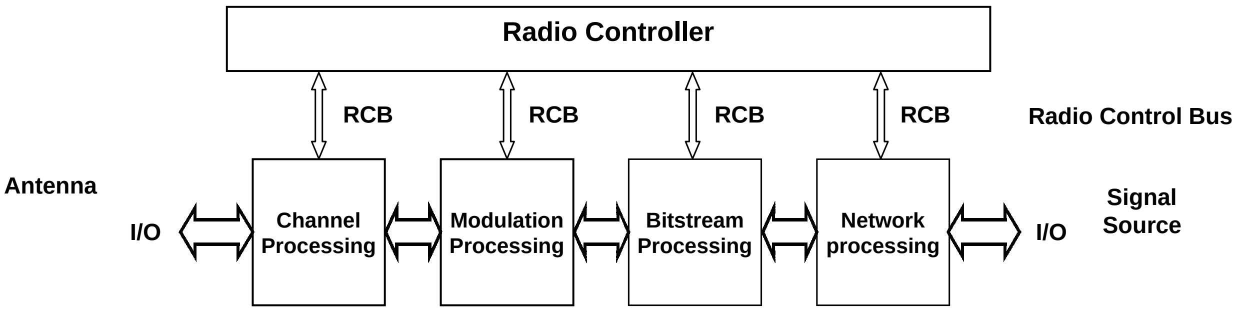

Figure 3: Typical Software Radio Architecture

A software radio must not place unrealistic demands on e.g. A/D and D/A converters by direct digitising at the RF stage (from the current technology point of view). Instead, some trade-offs are essential. Digitisation usually takes place on the first or second IF. This allows to relieve the A/D converter from excessive demands for the dynamic range.

Example of an Existing Software Radio

The M3TR (Multimode Multirole Multiband Tactical Radio) represents a completely new generation of high-performance Software radios. Contrary to conventional radios with fixed architecture the M3TR features maximum flexibility in terms of frequency bands, waveforms and functions satisfying the requirements of various user domains. M3TR is not restricted to military networks, but serves via loading the appropriate software also as a terminal in civilian PMR (Professional Mobile Radio) networks.

By forecasting technology trends the platform is designed in advance to cope with future applications, frequency ranges, additional functions and future COTS products. Evolutionary updating of modules fully exploits the technological advance of semiconductors and keeps the radio up-to-date, an implementation of the ETSI standard TETRA for example is planned. In fact, software configurability and upgradability by Pre-Planned Product Improvement (PPPI) is a key asset of a modular hardware and software architecture in order to reduce technology refresh insertion time and to lower costs.

The two manpack transceivers MR3000H and

Figure 4: Example of an Existing Software Radio (M3TR)

MR3000U providing seamless coverage of the transmission range from 1.5 MHz up to 108 MHz (model H) and from 25 MHz up to 512 MHz (model U) form the core of the M3TR transceiver family. In total, both units are designed for transmission and reception from 1.5 MHz to 512 MHz. So, with just two transceivers (MR3000H and MR3000U), the M3TR transceiver family covers the whole spectrum from short wave through to the UHF band.

Thanks to optimised protocols and waveforms M3TR attains high data rates for digital voice, real-time video and visual display data. Beyond Line of Sight (BLOS), e.g. HF offers up to 5.4 kbps user rate per 3 kHz channel, while in the Line of Sight (LOS) case VHF/UHF provides up to 64 kbps per 25 kHz channel suited for real-time data, video and Internet / Intranet access via the radios integrated Ethernet interface. In command systems this ensures among other things automated data exchange, for example for online position display and data distribution. PPPI (Pre-Planned Product Improvement) ensures to subsequently integrate planned and future methods in the equipment through simple software upgrades.

Different communications standards exist even within NATO and new ones are still being prepared. Examples are HAVE QUICK I and II, SATURN for UHF or STANAG 4444 for the shortwave band. Export waveforms like the Rohde & Schwarz proprietary waveforms SECOM and SECOS can easily be implemented. As a software-defined radio, M3TR can be made compatible with almost all existing EPM (Electronic Protection Measure) radios. It is interoperable with legacy communication systems and supports growth for new requirements.

Multiband	Multimode	Multirole
HF/VHF 1.5 - 108 MHz	Classic waveforms AM, FM, SSB ...	Radio Access Point
VHF/UHF 25 - 512 MHz	Civil waveforms TETRA	Combat Net Radio
Seamless coverage	Military Waveforms HQ, SATURN, SECOS, SECOM, 4444	Packet Radio Services
Civil bands	High Data Rate waveforms	Relais, Crossband Relais
Military bands	COMSEC/TRANSEC embeded	Selective links
	Digital voice	Gateway/Interface
	Future extensions	WAN/LAN
		Interfaces Standard, TCP/IP, UDP, EUROCOM
		Future extensions

Figure 5: Multiband, Multimode, Multirole Properties of the M3TR

The use of open system standards, like TCP, Ethernet, and well defined interfaces within the radio makes M3TR scaleable to match the communication requirements of different users and furthermore extendible to support further growth and changes.

Comprehensive multirole features allow its easy integration into communication networks, e.g. as a functional terminal in a subnet, e.g. CNR (Combat Net Radio: voice and data semi-duplex transmission in combat networks) or PRN (Packet Radio Net: multi-hop functionality for packet data transmission, adaptive routing of messages in case of jamming or relocation). But M3TR can also act as an interface between the subnets, REN (Range Extension Node: for user voice and data services established among radios out of range). Playing the role of a RAP (Radio Access Point) M3TR establishes the interface to fixed networks, e.g. ISDN/PSTN, LAN, WAN, and standardised bus systems, e.g. RS485, and to data interfaces, e.g. RS232, RS422 and MIL-STD-188-114A. It also offers intelligent gateway and relay functions.

Commercial off the Shelf (COTS)

In the past there were good reasons for military people to buy special Mil-equipment instead of civil products. Today there are no doubts that the trend to make greater use of COTS products does make sense particularly as user budgets are limited. However a careful analysis is necessary to optimise the user's benefit arising from this trend.

"Just buying COTS" does not necessarily secure all of the benefits they might bring to the development, maintenance and cost of systems. There arise some problems and sources of risk by the use of COTS products. First, COTS products may commit the user to proprietary interfaces and solutions that are not common with any other product, component, or system. Secondly, many security service systems have a 25- to 35-year lifetime, while the average COTS component today may be upgraded every 6 to 12 months. Thus any money that is saved by procuring a COTS product with proprietary interfaces will quickly be lost in maintenance and

logistics as products and interfaces change without the ability to migrate cost-effectively to other products and other technologies in the future. This situation becomes even worse when the vendor stops supporting the product without any substitutes.

So the question is not “Shall we buy COTS?” but instead:
“How can we make use of COTS to optimise our Life Cycle Management?”

It makes sense to subdivide the COTS question into four areas:

COTS equipment, COTS modules, COTS components and COTS communication protocols.

Buying **COTS Equipment** only is useful in special cases, where the services provided by civil technology fit well the user’s need concerning the type of service, availability, maintainability and security. Examples may be GSM, TETRA, UMTS and SATCOM. Problem areas can be proprietary interfaces and logistic aspects.

COTS Modules (or subsystems) providing special functions can be integrated e.g. into a radio unit. This appears to be a useful approach for wireless LANs, modems or chip sets for dedicated waveforms like TETRA or GSM. TETRA for example represents a typical system developed for professional users. These COTS products are available at reasonable costs. The chip sets are optimised in terms of size and power, simultaneously making re-engineering for software dispensable and cutting down the required development effort. The main challenge is that COTS modules very often have proprietary interfaces, which cannot be influenced without loosing the cost advantage.

The most efficient area of use of COTS in military applications is that of **COTS Components**. Semiconductor elements like A/D- converters (often said to determine the bottleneck of a software radio) and DSPs are roughly doubling its performance every 2 years. Keeping up Third-Party DSP-libraries are available at reasonable costs. Radio suppliers have been analysing part samples in terms of reliability, performance and critical parameters. Industry programs have shown the rightness of this approach. COTS parts reduced material cost by up to 50 %, increased part availability by tenfold and achieved reliability equivalent to military parts.

Another important aspect is to make use of **COTS Communication Protocols** like TCP/IP, UDP and X.25. This addresses the question of infrastructure, often underestimated in terms of complexity and cost. If commercial available protocols are used possibilities arise to stick on commercial available equipment like TCP/IP routers, switches, multiplexers etc. This will reduce system cost considerably.

The requisite to use COTS components is an essential part of the Software Radio concept. In advance the platform is designed to cope with future applications, frequency ranges, additional functions and COTS products in the future. An internally "open" architecture with stable interfaces between the modules makes it possible to cope with the frequent fluctuations in COTS products and keep the radio adaptable to advances in technology and changes in the marketplace.

The ´plug-and-play´ idea let an update be accomplished through replacing old components with new products the marketplace supplies. In fact, this idea introduces an **evolutionary, cyclic process** with a constant system change (Figure 6). In a cyclic process the products from the COTS

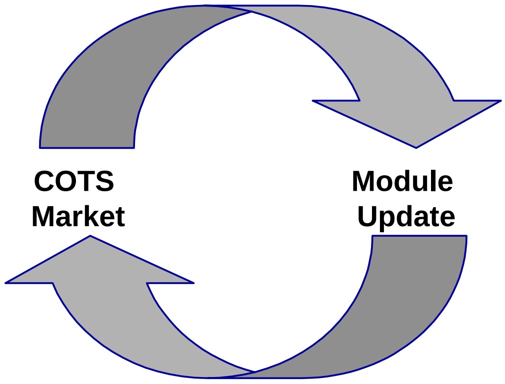

Figure 6: Evolutionary Cyclic Development Process

market are evaluated with respect to their technological advances e.g. in terms of signal processing power and power consumption and then integrated into the system (module update). Evolutionary and cyclic updating of modules fully exploits the technological advance of semi-conductors and keeps the evolvable system up-to-date. There will be no unexpected “vendor lock”.

Typical examples for this cyclic process arise from the permanent improvement of A/D converters and Digital Signal Processors (DSPs). In more or less periodic intervals, determined by the user or market needs, a re-engineering of the modules containing the A/D converter or the DSPs is performed.

Conclusion

The increasing speed of technology progress especially on semiconductor component level and the drastically reduced product cycle will cause a severe obsolescence problem of military radios. Life Cycle Management is getting more and more difficult.
To mitigate this problem the Software Radio approach is an appropriate solution.

Key is first to provide a horizontal approach, which means to establish a sharp separation between application (software), and hardware (radio platform), This property of the radio architecture allows development of application software running independently from the hardware configuration. The second key point is consequent and transparent hardware modularization which enables to replace functional hardware modules in a cyclic, ongoing process:

Whenever components are obsolete a reengineering of a particular module can be done which replaces the existing module by a new module, which makes use of newer, more powerful and eventually cheaper components.

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A Consideration of Obsolescence within the Design of Modern Avionics Test Systems

(25. October 2000)

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1. Summary

Considering obsolescence in avionics systems firstly leads to the obsolescence of the so called prime equipment. This means the equipment of which an avionics system is built. Normally the support equipment is more or less ignored or the analysis is postponed to a later date.

This situation was the challenge for us to work on a "Consideration of Obsolescence within the Design of Modern Avionics Test Systems".

We analysed today's situation and differentiated our analysis in the (COTS) market, customer requirements and technology.

During our analysis we decided to not only analyse the obsolescence situation within the test systems design, because obsolescence within the design of modern avionics test systems is only one of the determining factors. All factors have to be merged into a design concept inside of which single factors can't be considered stand alone.

Our solution – covering the requirements of the end user of our systems – consists of a design concept covering the test systems critical interfaces, test system standards and the philosophy of standardised units.

This approach ensures the flexibility in hardware and software to adapt quickly as needed on the commercial market and to guarantee the long term support as needed on the military market.

The approach is adaptable to various maintenance and service concepts providing each customer (nation) with its own In-Service concept supporting mobile and fixed service stations.

We are convinced that our concept ultimately benefits to our customer without ignoring the interests of industry.

2. List of Abbreviations and Acronyms

Abbreviation	Explanation
A/C	Aircraft
AGE	Aerospace Ground Equipment
ATE	Automatic Test Equipment
COTS	Commercial Off The Shelf
EADS	European Aeronautic, Defence and Space Company
GPATE	General Purpose Automatic Test Equipment
HW	Hardware
IETD	Interactive Electronic Technical Documentation
LRU	Line Replaceable Unit
RF	Radio Frequency
STTE	Special to-Type Test Equipment
SW	Software
TPS	Test Programme Set

3. Introduction

3.1. History/Experience

We, of the Airborne Systems Division of EADS Deutschland and Test and Services Division of EADS France, have a long lasting experience in the design, development and production of modern

avionics test systems. During the last ten years an additional test systems line - the Mobile Test Systems - has been established by both A.M. Divisions of EADS. Together we cover a wide range of test systems and applications.

The range of applications of Airborne Systems test systems extends from development test systems over production test systems right up to customer test systems. Various test applications for radar, electronic warfare, optical and general avionics equipment have been developed.

The range of applications of the test systems of Test and Services extends from development test systems over production test systems right up to customer test systems as well for the civil as for the military markets. More than 3500 test applications for avionics equipment have been developed.

Both divisions of EADS have the experience with more than one thousand of produced test systems, installed world wide both for Aeronautic and Defence applications.

3.2. The Problem

Our aim of looking at the problems of obsolescence within the design of modern avionics test systems involves a detailed analysis and the definition of a handy solution that can be easily applied to various test systems.

The title and contents of this article differ slightly from the others which dealt mainly with the so called prime equipment of the defence systems.

When dealing mainly with obsolescence problems within the design of prime equipment, there is a big risk that the associated logistic support will be neglected or left out.

Avionics test systems belong to the support equipment – Aerospace Ground Equipment (AGE) - that keeps the prime equipment in operation. Usually the main attention of military procurement organisations is drawn to the prime equipment. To our understanding it is very important, that the support equipment also has to be considered. This equipment has to support the military systems during their whole life cycle. This means, that the life time period is normally much longer than the development and production period of the prime equipment.

The awareness of the problems of obsolescence within the design of test systems comes up earlier than for prime equipment. Test systems normally are not flight critical, therefore they have not to fulfil the very hard qualification requirements of equipment that is use in an aircraft. For test systems COTS equipment can be used.

The traditionally long procurement periods of military equipment sometimes result in obsolescence problems even before the In-Service-Date of the equipment. The Military Customers, as well as industry, have to cope with new challenges.

During the last decades, test systems were often designed as Special to-Type Test Equipment (STTE) for a dedicated application, for a particular prime equipment.

In addition to the STTE solution, several approaches were made to develop universal test systems that were capable of supporting multiple applications. Unfortunately this traditional “Common Core Test Concept” sometimes leads to “overpowered” core systems and made upgrade programmes during the development and In-service phase difficult and expensive.

The exceedingly short innovation periods of commercial computers and measurement devices have forced EADS to optimise the concept for the development of Test Systems.

We analysed the situation of obsolescence in the design of modern avionics test systems. One important conclusion was, that we not only have to consider the obsolescence of the hardware components of our test systems, but that we also have to consider the software.

We concentrated our analysis on developing a conceptual approach, that fits in with the complete life cycle of our test systems.

4. Today’s Situation in The Design of Modern Avionics Test Systems

4.1. General

Firstly, we analysed today’s situation in the design of modern avionics test systems. We divided this analysis up into three different categories:

- COTS market
- customer requirements
- technology

All the above three elements touch the different obsolescence problems we have to cope with.

In a very early stage of our analysis, it was clear to us that obsolescence problems must be considered

not as stand-alone problems, but in connection with all the other elements involved. A stand-alone consideration can be made regarding individual components; e.g. if a PC board has to be developed and one or more components become obsolete. This stand-alone consideration, however, is not meaningful during the development of test systems that are made up of different equipment.

Therefore we developed a test system solution which covers nearly all aspects of the problems within the design of modern avionics test systems - including obsolescence as one major element.

How do we avoid, or better - mitigate -, the problems resulting out of obsolete items?

Before answering this question, let us look a little bit closer at the three different categories.

4.2. Today's Situation - COTS Market -

The COTS (Commercial Off the Shelf) market, especially for computers and measurement/stimuli devices, is expanding and changing faster than ever before.

Obsolescence and non availability of computer HW and SW, as well as obsolescence of measurement and stimuli devices, become a day to day problem.

Standards are no longer being defined by military requirements (only). Nowadays they are mainly influenced by the commercial acceptance of systems.

Commercial software is frequently upgraded, sometimes without notifying the customers; a downward compatibility is not always guaranteed. .

4.3. Today's Situation - Customer Requirements -

Ongoing changes in a nation's maintenance philosophy result in extreme flexibility within the necessary test system development. These changes are mainly driven by reduced budgets, changing operational requirements and adaptation to international / multinational programmes.

Increasing the complexity of the avionics systems, combined with the decreasing availability and capability of military operators, lead to a requirement for "Intelligent Test System Solutions".

The service periods of military operators is continuously being reduced, as is the quantity of qualified staff. The qualification of the operators is sometimes not sufficient for the tasks to be carried out. Therefore the test systems have to compensate this lack of qualification. In addition to the traditional tasks of a test system, the power of the integrated computer systems allow an increased spectrum of usability. There is an upcoming requirement for diagnostic capability, integrated training features and IETD (Interactive Electronic Technical Documentation).

Prime equipment upgrade programmes require - during the test systems life cycle - an implementation of several types/generations of technologies into the test systems. For example: during a mid-term upgrade programme, new electronic equipment is integrated into an old aircraft. This means, you have to manage different configurations of avionics equipment in parallel, that will have to be maintained by the test systems for a long time.

4.4. Today's Situation - Technology –

Decreasing budgets and reduced order quantities force developers of military test systems to design solutions based on commercial products in almost every new project development phase. The consequence is, that problems are appearing with obsolete items.

Traditional test concepts, such as large universal test systems, may lead to "overpowered" core systems, test systems being designed to cover all possible test requirements for the respective equipment or system. Ballast caused by commonality make upgrade programmes - during the product life cycle - difficult and expensive. The necessary flexibility is not available. Extreme short innovation cycles of avionics systems require a high flexibility and growth potential in the design of test systems.

In the past, avionics prime equipment had innovation cycles of ten and more years. Today these innovation cycles are much shorter, sometimes only a few years.

4.5. Requirements of the End User

Derived out of today's situation we have tried to sum up the requirements and concerns of the end user of modern avionics test systems. This list might not be complete, but we think that it covers at least all the main topics.

We always have to keep in mind, that the obsolescence problems can not be considered stand-alone, but within a complete picture.

A new test system should:

- take into account existing test systems already in use
- use an existing development & production SW where possible
- start with a low cost “Basic Core System”
- use a modular design, easy to maintain and to upgrade
- prevent redundant test-resources
- be configurable to specific purpose / national applications / country specific features (extendable on time schedule with additional resources and applications)
- allow TPS (Test Programme Set) programming to be independent of test-resources
- provide user friendly man machine interfaces
- facilitate TPS programming by prime equipment supplier
- allow easy interfacing of specific test devices needed only for one TPS

All these requirements and concerns should be addressed against the background of long term life cycle management over a period of 20-40 years.

You should know the customers requirements before you start to design and develop a test system. The military customer is looking for a long term serviceability of our solutions, but also wanting state-of-the-art solutions.

There is a British saying that describes that situation very well. We have “to kill two birds with one stone”. In fact, in reality: not two...but many birds ...

5. Solutions

5.1. General

Obsolescence is a problem which is with us to stay. Developers must find a way to minimise its effect. But it has to be clear, that the obsolescence problem has to be considered in connection with all the other determining factors.

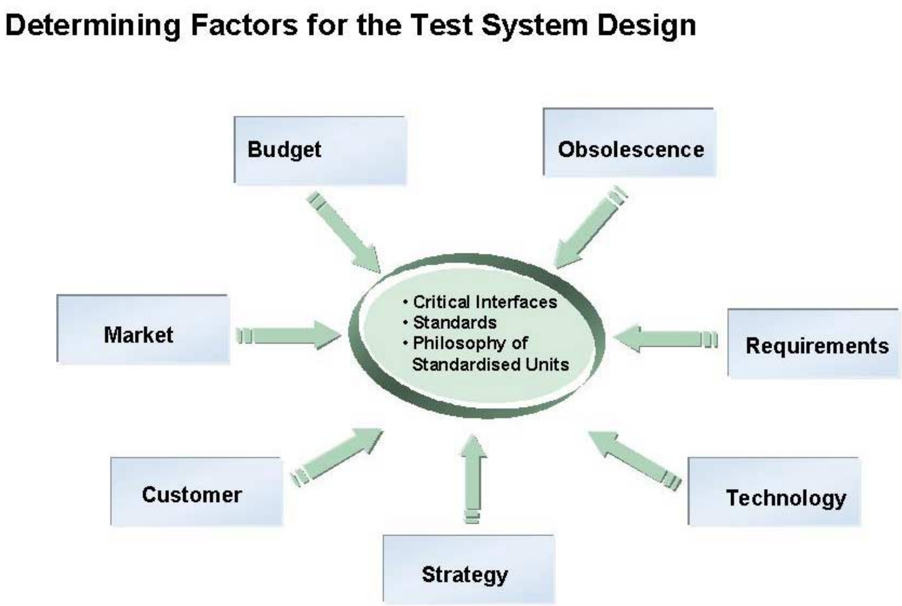

Illustration 1: Determining Factors for the Test System Design

One way of solving a large majority of the obsolescence problems is to

- analyse the critical interfaces
- consider the available standards
- use standard units

i.e. use units which can, without alteration, be built into numerous test systems.

During this process you have to be reasonable and as far as possible you have to foresee upcoming problems.

This methods not only reduces development costs, but also ensures that any up-coming obsolete items are dealt with, over a wide range of equipment, thus reducing the cost of the problem.

5.2. Test Systems Critical Interfaces

Defining and using Critical Interfaces between the subsystems and components of an ATE is a key factor for "The Philosophy of Standardised Units".

The choice of these interfaces defines the level of modularity and flexibility of the test system in terms of:

- Capability to host TPS and to grow in configuration depending on the units to be tested with the:
  - Capability to install easily TPS on the ATE,
  - Capability to configure the ATE to support a given set of LRU's
  - Capability to expand to support more LRU's
  - Capability to expand or change to support modified LRU's
- Capability to adapt to user's needs with the:
  - Capability to modify or replace the Man Machine Interface
  - Capability to add, modify or replace tools such as documentation viewer, test results, data bases, ……

.

- Capability to deal with obsolescence of components with the:
  - Capability to replace the test control computer,
  - Capability to replace the operating system,
  - Capability to add new ATE system buses,
  - Capability to expand the switching system,
  - Capability to add or replace test resources,
  - Capability to add or replace software components including compiler and run time system used for TPS.

The illustration 2 below shows the main typical interfaces needed to support the above requirements.

These test system critical interfaces are a challenge for customers and suppliers. They not only need to be carefully defined but also to be implemented by standard, insuring freedom of choice for components and long term support. This topic will be discussed in the next paragraph (5.3).

There are other key factors for success to consider such as (and not limited to):

- Avoid the change of critical interfaces,
- Keep requirements on a very high level
- Built systems based on commercial equipment (COTS)
- Buy from supplier that has many customers to have the chance of amortising/splitting the cost of obsolescence. If you are by yourself you have to pay 100%.
- Convince suppliers of key COTS item to buffer changes of components to avoid to pay charges for obsolescence, order batches not single items
- You need to be fast in the development of your systems, they shouldn't be obsolete when put on the market.

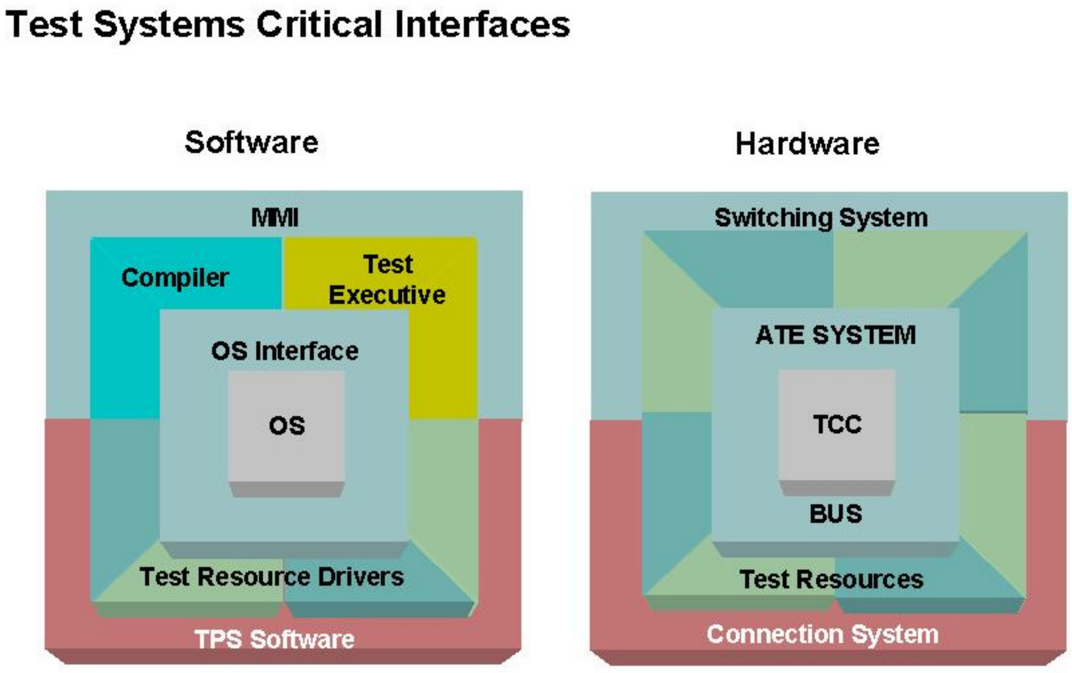

Illustration 2: Test Systems Critical Interfaces

5.3. Test System Standards

The critical interfaces discussed above should be implemented by standard ensuring:

- freedom of choice for components,
- long term support.

The technologies available today in the area of computers and instrumentation allow to find off-the-shelf industrial standards to match most of the ATE system critical interfaces.

However, these standards may change too fast to ensure at the same time the freedom of choice for components and a long term support matching the life cycle of the defence systems.

In order to address this problem we recommend to differentiate between:

- Very Critical Interface that ensures the portability and rehosting of TPS and protects most of the investment in test applications,
- Critical Interfaces internal to the ATE itself,

The Very Critical Interfaces are made up of the TPS programming language and of the ATE connection system. The standard in these area shall be stable for at least 20 years in order to protect the investment made in developing test applications. Industrial standard may not be up to the task without the effort of aeronautic and defence customers to define, use and enforce such standard.

On the other hand, the Critical Interfaces shall be off-the-shelf standard widely used by the industry. Their rate of change should be of at least 5 years. The customers should avoid to enforce these standards in order to make possible the best choice of components. The computer and software technologies available today made it possible to adapt and interface between the different standards at a reasonable cost, whenever changes cannot be avoided.

5.4. Philosophy of Standardised Units

With our background of a wide spectrum of different applications and the experience of many national and international programmes, EADS developed the “Philosophy of Standardised Units”.

The idea of The Philosophy of Standardised Units is not new. The principle uses a pool of existing standard units for the various applications comprising of:

- Controller
- Commercial Software
- Specific Software
- Digital Measurement Equipment
- RF Measurement Equipment
- Power Supplies and
- Mountings.

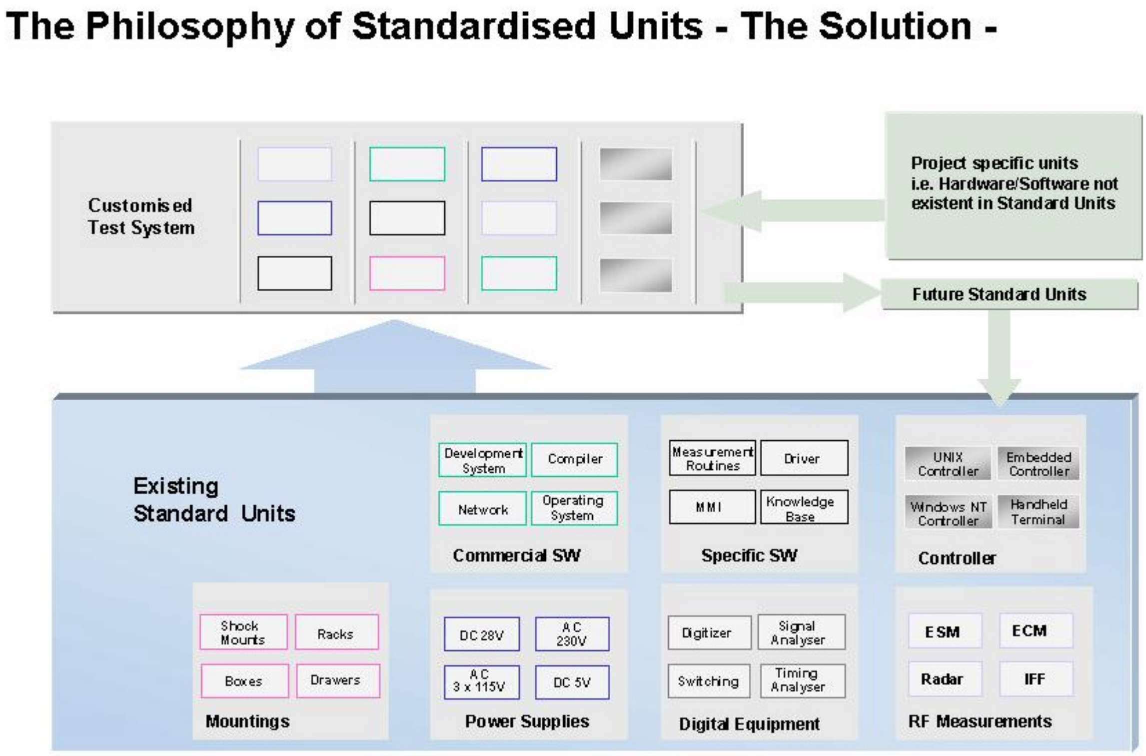

Illustration 3: The Philosophy of Standardised Units - The Solution -

The core system, and all the elements that are suitable for reaching the development goal, are built up out of this pool. They are amended by project specific units, i.e. hardware/software that is not yet existent in the pool of standard units.

In the next step, the product “New Test System” is analysed and all the new elements that are suitable for integration into the standard pool are identified and added to it. The “old” existing elements will be upgraded to keep the pool up-to-date.

The “Philosophy of Standardised Units” comprises the following technological and design requirements.

Technology

- To use state-of-the-art technology in test and measurement devices
- To maximise use of COTS Equipment
- To use technology with long term availability
- To prevent obsolescence

Design

- To define a test system design/architecture which achieves long term maintainability (i.e. allowing a change of test and measurement devices in HW and SW without changing the application)
- To maximise use of existing Test Programme Sets
- To allow growth potential
- To use international standards
- To create a common philosophy, useable for various/multiple maintenance concepts like shop, flight-line, modular, fixed, mobile, etc.

The first main advantage of the philosophy of standardised units is the flexibility in hardware and software, having the capability to react on the commercial market by being independent of types of equipment and/or manufacturers. This philosophy guarantees the long term support for the military market over the long support periods, that are required by the military customers.

To a certain extend interchangeability and even backward compatibility of the used test systems units can be accommodated..

The second main advantage is that it is adaptable to various maintenance and service concepts.

It is possible to provide each customer and each nation with its own In-Service concept without necessarily inventing a new test system. This can be achieved by using mainly the available pool. The concept also supports different applications of mobile - on aircraft, deployable - and fixed - development, production, shop - service stations.

Apart from the two cardinal advantages, it is worthwhile mentioning advantages like reduction of the cost for operator training and refresher courses by using well know elements and standard man machine interfaces.

The Philosophy of Standardised Units represents a design concept for test systems which allows flexibility for the insertion of new technology in the future and growth within the test systems.

6. Conclusion

We are sure that we are at the beginning of a development process in the design of modern avionics test systems that forces all involved companies to redefine their concepts. We are however also convinced that our concept of standardised units can't be implemented in a very short time.

Obsolescence in the design of modern avionics test systems is not only a matter of component obsolescence; measurement and stimuli equipment have to be considered as well as computer HW and SW.

A consideration of single HW or SW elements leads to a collection of single solutions. These solutions are often contradictory, and expensive.

Our solution points out a cost optimised way of integrating COTS products - including all the well known obsolescence problems - in a philosophy/strategy that is optimised for military requirements, e.g. long term availability/supportability.

The possibility of a continuous engineering process in the design and development of modern avionics test systems - taking into consideration already existing SW- and HW elements - guarantees a constant market presence at the front-end of the technological development.

The design concept is an evolutionary approach based on the existing test system design and it ensures maximum re-use of the current design to protect the investments already made.

All the above mentioned activities ultimately benefit our customers, but the active co-operation of the customer is required.

Our intention was to combine the best on whatever level necessary, and, if we may be so bold as to mention it, we think that we have achieved just that.

Management Issues in the Use of Commercial Components in Military Systems

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SUMMARY

Commercial off the shelf (COTS) products are being used increasingly in military systems, an approach that offers many advantages including lower initial acquisition costs, faster delivery to the front line and ability to utilise the latest advances in technology - a seemingly perfect match to the "faster, better, cheaper" ethos of modern acquisition initiatives. COTS products do, however, bring their own problems, including rapid obsolescence, lack of product control and fixed functionality optimised for the non-military market. In addition to addressing the complex technical issues that the use of COTS products brings, Defence Ministries and Industry will have to adapt their management approach and practices if the full potential of using commercial technology is to be realised, and dangerous pitfalls avoided.

This paper discusses some of the management issues that will have to be addressed and draws a number of lessons relating to the avoidance of obsolescence problems during the in-service life of a system or platform.

BACKGROUND

The use of commercial off the shelf (COTS) components is becoming an increasingly important aspect of the acquisition of military systems, particularly in the areas of information technology and communications. The use of COTS components should offer the potential to harness the rapid technological developments underway in the commercial world and to capitalise on the lower costs delivered by mass-market developments. Over recent years, these potential advantages have led to a view within the defence authorities and in industry that the use of COTS was going to solve many long standing problems in military systems, and would allow more capable systems to be delivered more quickly, at lower cost.

This initial widespread optimism is now being replaced by a realisation that while the use of COTS delivers many advantages, it also brings many difficulties and challenges of its own. These include more rapid product obsolescence, lack of control over product support and difficulty in predicting future developments. Many of these difficulties become most critical after systems have entered service and the obsolescence of their components has started to have a significant effect on support and development.

If these problems with obsolescence in COTS-based systems are to be solved and the attendant risks contained, then changes are required to the management of their acquisition and support. Much work has been directed at the *technical and design issues* relating to the use of COTS products. This paper, however, explores a number of aspects of the through life *management* of COTS-based systems, including initial acquisition, requirements management, managing upgrades, spares support and costing.

The paper focuses on information technology (IT) systems, as it is in this area that the rapid advances in commercial technology produce the greatest obsolescence problem. It is hoped, however, that the paper includes lessons of application in other acquisition domains.

This paper is based on work undertaken by the author for the UK Ministry of Defence (MOD) Defence Procurement Agency (DPA) and Defence Evaluation and Research Agency (DERA) Sea Systems Sector as part of a series of studies aimed at improving the COTS acquisition guidance available to UK MOD staff. The support of all those who contributed to these studies is acknowledged.

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COTS AND COTS-BASED SYSTEMS OVERVIEW

Terminology

Before embarking on a discussion of COTS it is necessary to define exactly what we are talking about, as common terms are often used inconsistently in this field. In this paper "COTS" refers to *commercial* off the shelf items, that is those that are developed for use in the commercial market, available from a catalogue or other description and delivered fully developed and ready for use. The paper does not specifically address other off the shelf acquisitions, such as the use of military systems bought with little modification (sometimes termed Military Off The Shelf, or MOTS) or the use of products developed by government (Government Off The Shelf, or GOTS). However, MOTS and GOTS items share a number of characteristics with COTS, and this article may offer a number of insights of value to those involved in such acquisitions.

Basic Characteristics of COTS Products

The basic characteristics of COTS components stem from the fact that they are developed for commercial, rather than military, purposes and that they are sold in large numbers (sometimes millions). COTS products have been designed to make a profit for the vendor, and not for the convenience of the (minority) military customer. Upgrades and changes are driven by predicted return on investment and not by some altruistic desire to improve or extend a product. The military user generally represents a small minority of the customers of a given COTS product, and military specific features are unlikely to appear high on the list of priorities for the vendor.

It is not the intention of this paper to provide a detailed description of the advantages and disadvantages of using COTS products. However, the following section summarise the main points, to put the management problem in context.

Advantages: The advantages of using COTS products have been advertised widely (possibly too widely). They include the following:

- *Low initial cost, with development costs amortised over many buyers*
- *Availability of established support arrangement, including development tools, vendor support and spare part support*
- *Reduced acquisition times by the use of standard pre-developed components*
- *Ability to capitalise on upgrades in technology developed for the commercial market*
- *Ability to adapt to meet new requirements*
- *Potential for enhanced interoperability*

Disadvantages

The use of COTS products is not all good news. In particular, COTS products suffer from

- *Rapid obsolescence, with support and spares lifetimes driven by commercial markets beyond the control of the defence sector*
- *Lack of product control with changes being made to meet commercial drivers*
- *Lack of Design Detail leading to difficulties in modifications and in safety and security certification.*
- *Mismatch with Military Standards*

COTS-BASED SYSTEMS AND COMPLEXITY

The complexity of developing a COTS based system is often underestimated. It is important to recognise that there is a considerable difference between buying a complete COTS system, sold commercially in the form or configuration that the military will use, and developing a system based on COTS components (referred to as "COTS-based systems" in this article). Lack of recognition of this COTS characteristic has been at the root of many management issues in the development of military COTS based systems.

There has been an impression that COTS-based systems are easy to build, and therefore the use of COTS will automatically reduce design complexity and hence cost, timescales and risks. This feeling has, to some extent, been generated by an incorrect extrapolation from the observed characteristics of complete COTS system purchases. When a *complete* COTS system is purchased, the system design has been carried out by the vendor and its complexity is hidden from the purchaser. Design cost has been amortised over a large number of purchasers, reinforcing the impression that the cost of COTS-based system design is low.

Unfortunately, this assumption is not valid for a typical military COTS-based systems, which will contain a large number of COTS components or products, each of which is *purchased separately from the vendor* and then integrated to form a new system configuration, *never previously developed and unique to this application*. This integration will involve the configuration of individual products to match their environment and typically require the development of custom code to provide interfacing functionality and to meet the specific system requirements.

The unique configuration will also place the individual components in a new environment, never tried before, and this may well expose incompatibilities previously unknown to either the developers or the COTS vendors. The situation is further complicated in most military systems by the need for bespoke applications to meet specific military requirements and the need to incorporate bespoke legacy applications.

As a consequence of these issues, COTS-based systems require at least as much effort in system design as any system based on bespoke components. Indeed, it may be argued that the fixed functionality and performance of

the COTS components place *greater* constraints on the design of the system, forcing more iteration between system levels. This design iteration will not cease when the initial design is completed.

In summary, the combination of a unique design, the use of a large number of inflexible components in a new environment and a mix of bespoke and COTS elements, means that, contrary to widely held opinion, large COTS-based systems are inherently complex. Management plans that fail to recognise this complexity are likely to underestimate the effort and time required for system design, both during initial acquisition and during the in service life of a system.

CONTINUOUS DESIGN PROCESS

As the underlying COTS components are replaced by others (as they surely will be), the system configuration or design needs revisiting to address the characteristics and functionality of the new components. In some cases the changes will be minor, for instance when a component is superseded by another without affecting its functionality or interfacing, and the effort required will principally be focussed on configuration management. In other cases, however, the withdrawal of support for a key infrastructure component (such as an operating system or database) may necessitate a major redesign with impact on many other components in the system.

The interrelated nature of IT products can lead to a domino effect, with the change of one component requiring the replacement of many others. For example the change to a new processor could require a new operating system, which may in turn require application programmes to be replaced. It may also require the redesign of bespoke application software developed for the system. The unique nature of a given military system also means that with each change, components may be placed in a new environment, which can expose shortcomings in products not previously uncovered. This will need to be resolved before the system is put into service. Each major increment will, of course, also bring the need for extensive testing and revalidation.

The rapid turnover of COTS products and the consequent changes to the system design and configuration means that *a COTS-based system is in a state of continuous design, throughout its lifetime*. (See Figure 1)

This fact needs to be recognised in the through life management of a COTS-based system, and suitable resources and funding to support the continuous design process must be secured.

MAGNITUDE OF TECHNOLOGY CHANGES

It is readily apparent that the technology on which COTS products are based will change during the lifetime of a typical military system. While it is universally recognised that that changes *will* take place in technology, discussions with a wide range of military projects suggests that the *magnitude* of the changes is often not appreciated or taken into account in project management planning.

To get some idea of the likely impact of technology changes on military systems we need to look forward some twenty five years (at the end of which many systems currently in the concept stage will still be in service). If we look *back* twenty-five years, to 1975, we can see how far commercial information technology has moved. In 1975, there were no desktop computers, no Internet (in the form we would recognise today) and no mobile phones. Object oriented programming was an obscure specialist technique and interfaces were (at best) text based. The microprocessor was in its infancy (the 6 MHz 8080 and 6.4 MHz 6800 were both launched in 1974). Windowed user interfaces, mice, LCD screens, the world wide web, TCP/IP and HTML were still all years in the future. Figure 2 shows some of the key events over the last twenty-five years. In short, we can see that commercial technology has changed beyond all recognition.

It is generally considered that the rate of change of technology has been increasing over this period, and today new concepts and ideas are being introduced at a high rate. (The life of a commercial software product is typically 12 - 18 months before it is replaced by a new version, and some 2-3 years before all support is dropped.) It is against this background that we are asking industry to develop systems that will last for twenty or more years beyond In Service Date (ISD).

Some changes during this time will be predictable. The cost of processing power will continue to fall, bandwidth available to commercial users will expand, and the cost of storage (volatile and non-volatile) will reduce. However, as the last ten or twenty years has shown us, the way in which these developments will be exploited in the commercial world is impossible to predict.

If specific technology trends can't be predicted, those considering the design and implementation of COTS-based systems must consider the *magnitude* of the changes that are likely to take place. In the next 15 years we will see changes as far reaching as: the removal of keyboards and screens as interface devices, the demise of a web based approach or indeed of the internet as we know it, the advent of effectively unlimited bandwidth for commercial users (with the subsequent transformation in commercial system architectures and techniques) or the demise of the concept of a workstation running software. It is not suggested that all (or any) of these specific possibilities will definitely occur, but changes of this magnitude are certain to arise. The challenge to military COTS-based systems designers is to develop architectures and design and management approaches that can deal with this level of innovation during the 25-year life of a typical military project.

The rate of change of technology means that a system will have to deal with more than just component obsolescence during its lifetime. In the typical 25-year life of a system, commercial technology may be expected to have changed beyond recognition. Current standards, design approaches and architectures will have been superseded and forgotten. There is very little scope for assuming that we could continue to use today's hardware and software solutions throughout the life of a military COTS based system. Even though we do not know exactly what the changes will be, we must plan to manage this level of technology change if fatal obsolescence problems are to be avoided.

REQUIREMENTS MANAGEMENT

All studies into the use of COTS in military systems emphasise the need for a suitable process to manage requirements and requirement trade-offs. It is considered, however, that we have yet to see a system or management approach that handles this task satisfactorily.

If a COTS product is to be used in a system, there is very little scope to change its functionality (although many products have parameters and settings that can be changed). When a COTS product is selected, it is highly unlikely that its characteristics will match precisely those of the requirement. This implies that it may be sensible to accept the capability offered by the product despite the fact that it is not precisely what was originally demanded by the user.

As the design becomes more detailed, and different combinations of products are selected, then the match of these to the original specification will need to be assessed. In some cases the advantages (low price, availability, good support) offered by a COTS product will outweigh the fact that it does not match the original requirement. In other cases, there may be a need to select a different product, or use the product and enhance its capability by the use of other products, or by producing some bespoke application code to provide the required functionality. In many cases, of course, a COTS product will have features that were not originally included in the requirement, but which are of value to the customer. Design decisions such as these can only be carried out if the design team has the skills and experience to understand the needs of the user, and the impact of any possible design changes. This will require a very close relationship between the designer/system integrator and the user community.

Trade-offs between cost, risk, availability and functionality will continue throughout the life of the system. As obsolescence forces the change to a component, the selection of its replacement will require the same assessments to be carried out, possibly leading to further agreed changes to the user's expectations/requirement. The timescales of changes will often mean that later fielded systems are different from their predecessors, leading to the potential for a range of different systems in service, each developed during trade-offs for particular systems or batches of systems.

An additional feature of COTS-based systems is that the use of commercial technology should allow the rapid exploitation of advances in the commercial world. This, in turn, means that COTS-based systems offer the chance to enhance the requirement in a cost-effective manner. In particular it should allow military systems to exploit new applications and methods of working in the commercial world. The management of upgrades will need careful control; this is discussed further below.

The aspects discussed above indicate that if the full potential of COTS-based systems are to be exploited, then a close and dynamic relationship is required between end users, procurement staff and industry. This close working relationship will be required throughout the life of the system, as trade-offs and requirement developments are initiated by COTS product changes forced by obsolescence and upgrades. Such relationships are rare, with traditional acquisition approaches often leading to a confrontational relationship, rather than close cooperation.

A key to making sound decisions in this dynamic environment will be a clear understanding by all parties of the way in which commercial technology is advancing. Such knowledge will permit a realistic vision of what is likely to become feasible in the near future and will assist in foreseeing and managing potential obsolescence problems.

In summary, COTS-based systems involve considerable effort to be placed on requirement negotiation and trade-off. This process needs to involve all stakeholders, and many of the detailed decisions will continue to be required beyond Main Gate. Requirements evolution will continue throughout the life of the system, as new products are delivered by developments in technology and old products become unsupportable.

The use of rapidly developing commercial components brings the need for a paradigm shift in requirements management. Conventional tools and methods are inadequate to either capitalise on the huge advantages that COTS products could deliver or to avoid the pitfalls of obsolescence. A much greater emphasis is required on involving all stakeholders and a new approach to requirements management is required, based on continuous requirements evolution. If the full potential of COTS-based systems is to be exploited, then a close and dynamic relationship is required between users, procurement authorities and industry.

COST FORECASTING AND FINANCIAL MANAGEMENT

Successful project management includes a need to predict future costs, and plan future spending and manage the programme to remain within allocated budgets. In the procurement of military systems, it has long been recognised that initial acquisition costs are heavily outweighed by the costs of in service support, and this has recently led to an emphasis on through life or whole life costs.

Unfortunately, however, *accurate prediction of the long-term costs of a complex COTS-based system is not possible*, for a number of reasons. These include:

- A lack of suitable cost models.
- No agreed MOD/industry process for the maintenance and development of COTS-based systems through life, making assessment of through life costs infeasible.
- Volatility and unpredictability of future developments in technology.
- Unpredictability of the direction of future commercial developments and their applicability to military systems.

This poses particular problems in military system acquisition, in which acquisition authorities are expected to provide reliable through life cost estimates early in the programme to support the choice of contractor or solution. There may be reasonable assessments of costs through the initial acquisition of the system but cost estimates beyond this will be subject to significant uncertainty.

It is not possible to accurately predict the through life cost of a COTS based system. This fact needs to be recognised in the planning and funding of systems, and runs counter to most standard defence acquisition strategies. Failure to plan for this uncertainty, and to secure adequate flexibility in funding will delay the introduction of updates, leading to increased problems with obsolescence and support.

SAFETY AND SECURITY MANAGEMENT

The use of COTS products in systems introduces some significant difficulties with regard to system integrity assessments, in particular for safety and security assessment and accreditation. Those problems are caused by a number of factors, including the way that COTS products are developed and controlled, the lack of information and the rapid obsolescence and replacement of products.

The military world has traditionally insisted on systems meeting specific standards regarding product safety. It can generally be assumed that COTS products will not have been designed to meet these specific standards , although in some cases equivalent civil standards will have been addressed. In some cases these standards will be acceptable for use in the military environment, and the explicit requirement to meet a military standard can be waived. If this is not the case, however, the military system procurer may have to gather further evidence or undertake specific tests on the proposed or delivered products to assess their safety. Such tests may not, however, be cheap and gaining assurance that they will remain valid for all deliveries may be difficult. For example the source and chemical make-up of cases and components may change between batches, and toxicity tests undertaken on a sample product may not be representative of all such products. If assurances are required that tests will remain valid, then a manufacturer may have to establish additional procedures or a different product line, in each case this will invite additional costs.

COTS software presents particular difficulty in safety related (or safety critical) systems, because lack of control over the development method and lack of information render standard methods of assessing software quality infeasible. In particular:

- COTS products have already been designed, and so design and coding methods (such as the use of formal methods) can not be influenced.
- Code listings are not generally available for COTS software products, rendering static code analysis impossible.
- COTS products will generally have been designed to less rigid standards than those demanded by, for instance, Def Stan 00-55.
- Large software infrastructure components (such as operating systems) are of a complexity that renders exhaustive testing impossible.

Even if a product had been analysed and accepted, the short lifetime of COTS products can force repeated analysis. Any analysis will take time, and this may introduce delays in re-confirming the safety or security accreditation of the system.

These difficulties can be mitigated by good system design (for instance by partitioning of safety critical elements of a system, or by adding additional safety controls), and by using alternative assessment methods (for example assessing the general quality of a company's software or gathering evidence on the reliability of the COTS software product). The selection of the supplier should include an analysis of his credentials and qualifications in supplying safety critical software. The assessment of the system and the accreditation task itself will be simpler if the supplier has a suitable track record and is familiar with the development and accreditation of safety critical items.

The safety and security accreditation of COTS based systems presents considerable technical, design and management challenges. The difficulties and cost of initial and ongoing system accreditation must be considered in the development of COTS-based systems and in the selection of system contractors. Delays in the introduction of upgrades caused by safety and security issues will increase obsolescence problems.

MANAGEMENT OF SYSTEM UPGRADES

The key to successful ongoing support and improvement of a COTS-based system will be the development of a suitable infrastructure, into which new components and products can be inserted, combined with the development of a suitable management regime. The implementation of an open, flexible infrastructure, capable of adaptation, extension and scaling to counter obsolescence and to provide new functionality and capacity, is not a simple task. Those financing and approving programmes will have to take into account that it is more expensive to develop, implement and maintain such an infrastructure than to develop one that will simply meet the current demands.

Management of upgrades

The terminology relating to system modifications and upgrades is complex, diverse and inconsistent. It is important to distinguish between at least two different categories of system modification. These are:

- Changes driven by obsolescence ("technology refresh")
- Changes to increase capability ("capability upgrades")

Having made that distinction, however, we must recognise that there are limited opportunities for upgrades, and the need for cost effectiveness means that any significant system upgrade event will include elements from *both* of these categories. As the different categories of modification carry different responsibilities for specification and funding, this has the potential to introduce management difficulties.

The management of upgrades in a COTS-based system is a far from simple problem. It involves a wide range of stakeholders with conflicting interests, and successful resolution will require understanding of many viewpoints and interests. There are many tightly interrelated factors to be considered in managing system development and in planning individual upgrade events. These include cost, time required to implement the upgrade, time required for preparation, risk, obsolescence pressures, availability of COTS and legacy components, platform programmes, links with other programmes and specific operational demands. (Figure 3). These various aspects will need to be assessed and traded off in any particular upgrade, and this will require input and understanding by all stakeholders. The complex interrelationship between the various stakeholders will be simplified by clear understanding of their individual aims and responsibilities. Managing the upgrade process will require the co-operation and support of all stakeholders.

A through life view needs to be taken by all parties, and each must have an incentive to act in a manner consistent with getting overall value for money on a through life basis. Amongst other things, this means that:

- Those controlling the finance must recognise that there will often be an up-front cost to keep a system flexible enough to accommodate future (but currently unknown) capability upgrades.
- The acquisition authority must recognise that industry needs to make a profit, and enter into arrangements that allow for this while still ensuring good value for money.
- Industry must be given the incentive to invest in system upgrades and support facilities confident in the belief that these will contribute to increased return at a later date.
- The long term strategy for maintaining and upgrading the system needs to be agreed early in the programme, in order that the through life costs can be realistically estimated and suitable support arrangements put in place.

Management plans must recognise the complexities of managing technology refresh and capability upgrades. Successful management of upgrades will require the cooperation of many stakeholders, often with different and conflicting priorities. Successful management of upgrades will only be possible if there is a close and trusted working relationship between MOD and industry. The confrontational approach that is typical of many current procurements will preclude cost effective management.

CONTRACTOR LOGISTIC SUPPORT

Contractor Logistic Support (CLS) contracts, where the contractor is given the responsibility for supporting a system for a given period, are often seen as a standard solution for reducing risk on acquisition authorities and gaining cost effective support for a system. However, for COTS-based systems, there is a danger that, unless supported by other incentive schemes, the traditional CLS contract can contribute to *increased* obsolescence and higher through life costs.

As has been pointed out, COTS-based systems suffer from rapid obsolescence, leading to the need for continuous technology refresh if they are to remain supportable. If a contractor accepts a firm price CLS contract for, say, the five years following ISD then he will be under an obligation to support the system, and hence it will be in his interests to keep the system free from obsolescence problems during this period. However, he will not wish to spend more money than is necessary to meet his contractual commitments. As the end of the CLS period approaches, the system will be in a state that no further technology refresh is required to maintain the system for the remainder of the period. This point will probably be some three years before the end of the period. The contractor might not, therefore, undertake any work to mitigate against future obsolescence during these three years. The result will be that at the end of the CLS period, the system will be about to become unsupportable.

To avoid this, there is a need to provide the contractor with the incentive to keep the *through life* cost of obsolescence low. A fixed CLS period, with no further obligation or commitment, will only provide an incentive to keep the obsolescence cost low during the contracted period. It is clear that we will have to look at innovative solutions to this problems. These will involve working closely with their suppliers to achieve solutions that are of mutual benefit. For these solutions to be successful through life, the benefits will have to be capable of being shared between government and industry.

The management of CLS for a COTS-based system requires careful consideration, as the conventional "hands off" approach brings particular problems. A closer working relationship, and cost and risk sharing, will be required if a successful support regime is to be maintained.

SPARES SUPPORT AND CONFIGURATION CONTROL

The use of COTS components in a complex system introduces some significant difficulties in the domain of configuration management and spares support. These challenges are a direct result of the fundamental characteristics of COTS products, including:

- short periods of commercial availability,
- interdependence between products (including hardware and software interdependencies)
- the potential supply of compatible COTS components from a number of suppliers.

The principles of configuration management are as (or more) important in COTS-based systems as they are in traditional systems. However the widespread use of COTS products introduces a number of additional complexities to configuration management. These include:

- frequent design changes,
- lack of configuration information for COTS products,
- inter-dependence between hardware and software,
- need to track the installation of new versions even when they appear to be completely interchangeable,
- the many minor changes made to new COTS software products,
- the lack of reliability data.

The short supply lifetime of COTS components and the diversity of configurations make the supply of hardware spares difficult to manage. As new products appear, and old versions are no longer available, there will be a requirement to certify new products for use in a system and manage their supply and availability for the different system configurations in use.

The use of COTS components brings the potential for a configuration explosion, with each installation (and each sub-system within the installation) being significantly different from others. This in turn brings complexities for spares and support management. A balance will have to be struck between containing this diversity and the cost of limiting implementations to a manageable subset of configurations.

Whole life buys (or "Through life buys" or "Lifetime buys") are often proposed as a strategy for dealing with hardware obsolescence. Unfortunately, experience has shown that these are rarely a realistic solution, for a number of reasons:

- *Inter-relationships between software and hardware* - COTS-based systems often exhibit a strong interdependence between their components, and particularly between the software (both infrastructure and application) and the hardware on which it runs. In the commercial world, new processor upgrades are commonplace, and as new software is developed, support for older hardware is often dropped. The consequence of this is that if hardware is not upgraded then in a relatively short timescale, software cannot be upgraded further with a direct effect on the capability of the system to react to new threats and requirements.
- *Loss of ability to exploit new technology* - If the infrastructure hardware and software becomes frozen, then the capacity to modify the system to add new functionality is reduced. Software packages that the users may like incorporated into the system will not be available, because a modern commercial package will expect and require up to date or recent versions of the operating system, processors, peripherals etc.
- *Need for system development support environment* - In the longer term the decision to limit the system to obsolete technology will affect the development environment as well as the system itself. For example, as new software languages are developed, compilers will only be written for newer processors and operating systems. This will further limit the ability to upgrade the system.
- *Difficulty in predicting numbers* - It is difficult to gather or obtain MTBF figures for COTS products, either because the data has not been gathered, or because they have relatively short life histories, or because they have not been used in representative environments. This lack of data, combined with the possibility of the spares being rendered unsuitable by other changes in the system, represents a major risk in costing and undertaking whole life buys of spares.

Spares support for COTS-based system presents a complex management challenge, with the potential for serious configuration management problems. The principles of configuration management are just as important for a COTS-based system as for any other procurement, but the use of COTS products brings the potential for an explosion in system and sub-system configurations. This diversity carries a cost overhead,

and will need to be contained. It is essential that this issues is addressed in other management areas, including technical design, funding and support management. The use of through life buys of spares is rarely an adequate solution to these problems.

CONCLUSIONS

Military acquisition is moving into new and uncharted waters. The use of COTS products as the basis for military systems brings many advantages, but it also brings many challenges. To meet these challenges will certainly require new technical skills and an understanding of the characteristics of COTS within procurement organisations. However, COTS-based systems also bring management challenges, many of which run counter to current working practices in military acquisition. If we are to rise to these challenges, and harness the potential advantages of COTS, then a change in management culture and philosophy will be required, allowing the introduction of new management approaches, representing and balancing the needs of all stakeholders in government and industry.

BIOGRAPHY

Richard Ellis is a Principal Consultant with Stratum Management Limited and has over 12 years' experience of system acquisition management and research for the UK Ministry of Defence (MOD). He joined the British Royal Navy in 1977, and during a 13 year career as a Weapon Engineer Officer gained a BSc in Electrical Engineering and an MSc in Intelligent Systems. Since leaving the Royal Navy in 1990, he has worked as a technical management consultant with Crew Services Limited and more recently with Stratum. During this time he has supported a wide range of MOD projects, both in the Procurement Executive and Defence Procurement Agency and in the Defence Evaluation and Research Agency. Much of his work in 1998 - 2000 has been in the development of MOD acquisition policy for systems based on Commercial Off The Shelf components. In addition to his work in military procurement, Mr Ellis is also the Director of Advanced Technology for ideadollar.com, an internet based innovation company, and is actively involved in the UK artificial intelligence community.

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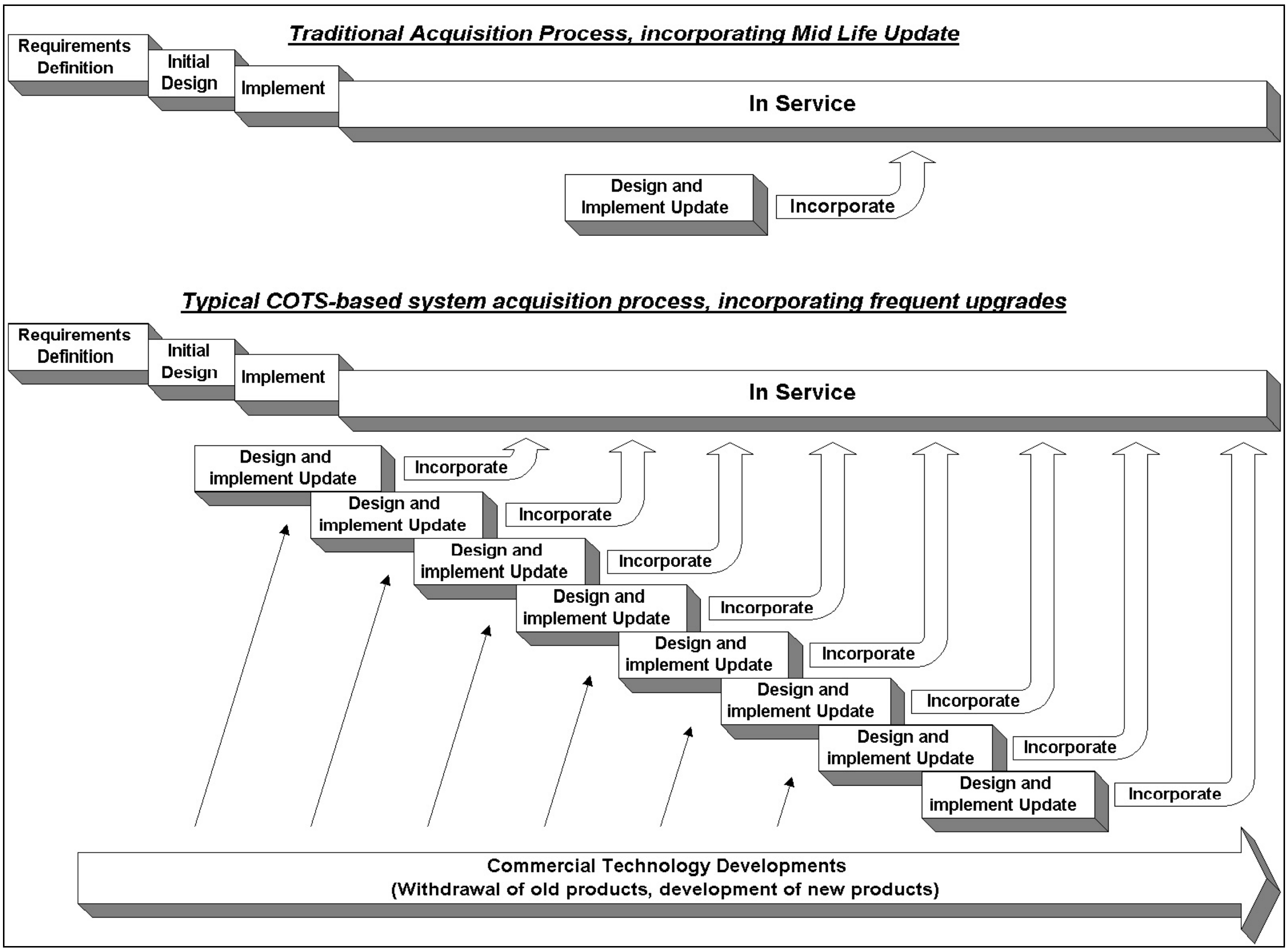

Figure 1 - Comparison of traditional and COTS-based system acquisition lifecycles

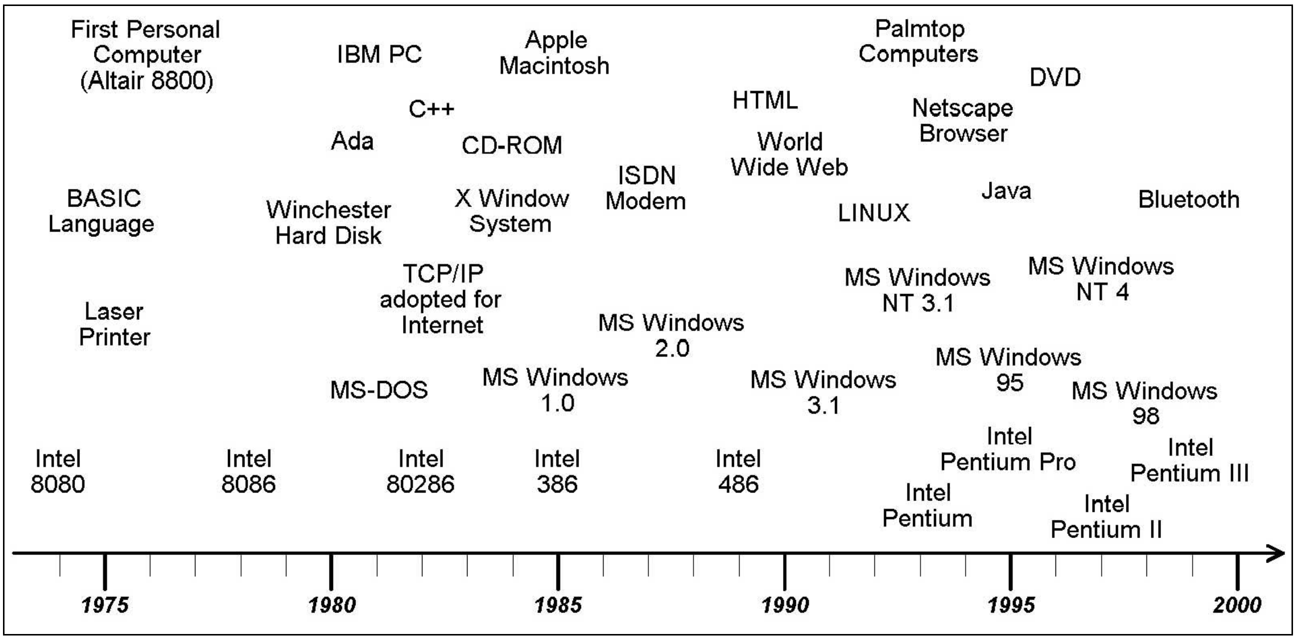

Figure 2 - Selected events in the development of commercial technology

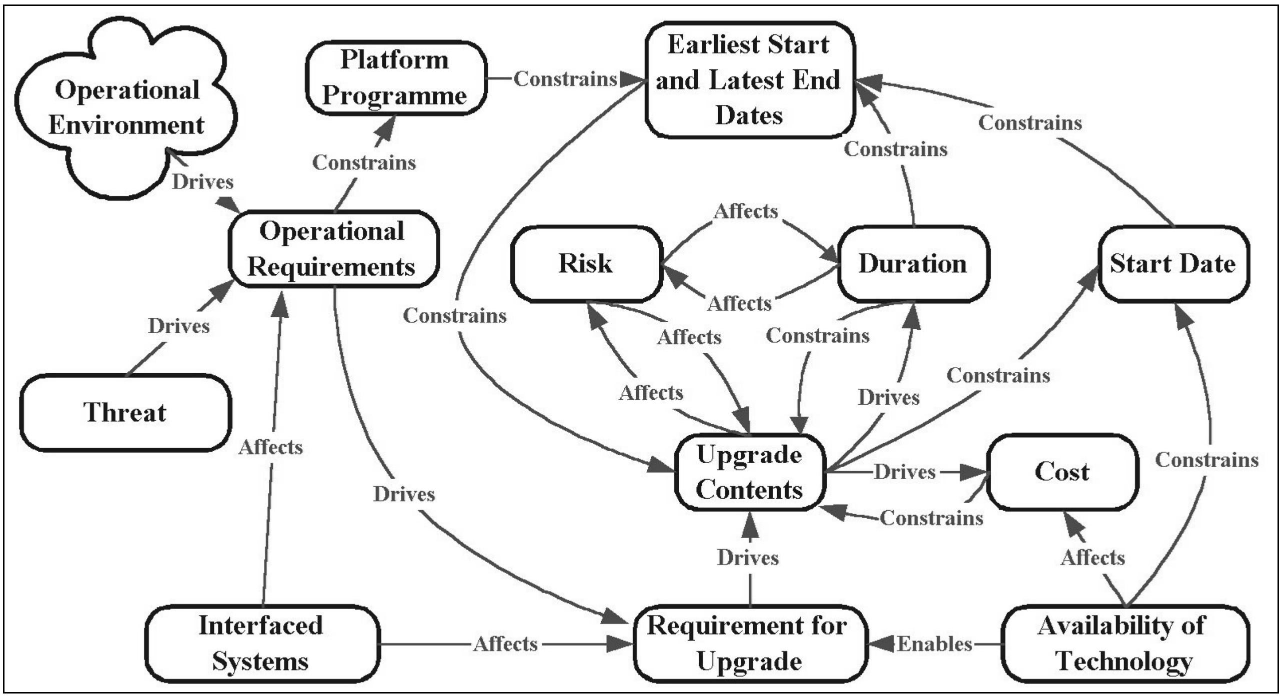

Figure 3 - Influences on system upgrades

Software COTS Components – Problems, And Solutions?

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Summary. COTS components offer a solution to many obsolescence problems, but certain COTS items can also introduce their own difficulties. Commercial operating systems, for example, play a key system role but are single-source and black box, denying the user both the visibility and control of a bespoke item. Open source software in general, but the Linux operating system in particular, seems to offer many of the advantages of COTS but with the added benefit of full access to the source code. However, the widespread adoption of Linux presents not only opportunities but some potential difficulties, for which a possible solution is a dedicated focus within the defence community.

Background to Paper. The Defence Evaluation and Research Agency (DERA) is the prime source of research for the UK Ministry of Defence (MOD), and also provides a major source of independent advice to MOD during all stages of systems procurement and deployment.

The Systems and Software Engineering Centre (SEC) is a relatively new body within DERA, being established in 1994 to act as a focus for professional software (and soon after, systems) engineering within DERA. The majority of its complement of about 260 staff have an industrial background.

The SEC has responsibility for the systems and software standards and practices used across DERA (which has a staff of around 11,000). It provides the editor for the draft ISO standard (ISO15288) on systems engineering and is influential in setting the systems engineering direction of MOD's procurement arm, the Defence Procurement Agency (DPA). It provides systems and software engineering support to a wide range of programmes within DPA, and increasingly to the Defence Logistics Organisation of MOD. The SEC is also leading in the field of capability assessment and evaluation, eg in developing and applying various Capability Maturity Models (CMMs). The author is the SEC's Technical Manager.

Despite this background, it should be made clear that this paper does not constitute the results from a MOD-funded research programme, nor does it represent the official view of MOD, DERA or the SEC. Rather it captures the personal views and thinking of the author. However, the author is pleased to acknowledge the rich source of ideas he has encountered in the SEC, DERA, MOD, Defence Scientific Advisory Council (DSAC) working parties and other contexts.

Some of the ideas addressed here are included in a recent paper in the Journal of Defence Science, published by DERA.

Introduction. Commercial components[1] that can be used in defence systems may take several forms:

- A common commercial item from the civil world (eg a PC or Land Rover)
- A specialised item from the civil world (eg an inertial navigation system box for an aircraft)
- A “standard” item from the defence world (eg a gun sight)
- An item that has been used before but just needs “a little change” to make it meet its new purpose – especially true of software
- A small component (eg a processor chip)
- A full service (eg satellite communication)

Whichever kind of component is considered, there are some common issues that arise when thinking about a defence system in which commercial components play a significant part[2]. These issues are highlighted most starkly when the item is a truly commercial (COTS) system component. Hence, this is the case considered in this paper.

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[1] In this paper, the term “component” is generally used broadly and is intended to encompass sub-systems; it is not intended to imply the lowest level in a decomposition.

[2] While acquisition of a capability might be more appropriate to consider than acquisition of a system, systems are considered for convenience.

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While many of the issues discussed apply equally to any kind of COTS, the emphasis of this paper is on software items. There are a number of reasons for this:

- Software is the difficult and expensive part of most systems
- Software COTS items are often the most sophisticated and complex kind of component
- Many software COTS items change rapidly

COTS and Obsolescence. COTS items have a particular attraction when considering obsolescence management. They typically have a longer lifetime than bespoke components because they have a much broader customer base (or at least are cheaper over a given lifetime because maintaining bespoke items is expensive). There is also often an opportunity for multi-sourcing that is very significant.

More generally, compared with a bespoke approach, a COTS-based development often offers many advantages, including:

- Reduced costs
- Reduced timescales
- Increased reliability through exploitation of proven items
- Exploitation of civil research and development (R&D) investment, which globally has far outstripped defence-focused R&D
- Accelerated introduction through familiar user interfaces that facilitate training, etc
- Increased opportunity for multi-sourcing through open standards
- Improved interoperability between defence systems and organisations, through standardisation
- Improved interoperability between defence and non-defence systems and organisations, again through standardisation

It is important to note that a COTS-based solution will not necessarily offer all these advantages. For example, the COTS item might be proprietary and single-source, while still delivering all the other advantages listed above.

Impact of COTS. The potential benefits are thus great, but it is vital to consider carefully how the use of COTS impacts some key areas:

- Military capability
- Systems development
- System acquisition and support

Capability. COTS is a powerful influence towards a “level playing field”. By its very nature, a COTS component must be considered to be available to any country and organisation. We must assume that potential enemies can:

- Exploit the same COTS components in their own systems
- Infer how we might use them in our systems
- Explore their weaknesses
- Develop countermeasures of various kinds
- Perhaps exploit upgrades to the COTS components faster than we can

Because of their ubiquitous nature, COTS items are a particularly vulnerable part of a system. Where the item is something like an operating system, we can expect any flaw such as a security weakness to be identified very publicly. Perhaps more dangerous is the community of semi-underground “crackers” - individuals, and sometimes organisations, who spend time identifying weaknesses in COTS software items and then publish or exchange this information on the Internet.

Conversely, it is possible to exploit this published information and counter any weaknesses rapidly - assuming the underlying mechanisms for rapid upgrading are in place, a crucial point. Of course, if the affected item is a COTS package over which we have no direct control, the best we can do with the information is to press the supplier for a fix and attempt a “work around” until it arrives.

System Development. A key characteristic of most COTS components is that they are “black boxes”. This has a number of serious implications:

- We cannot be sure what they contain; they may have in them – perhaps deliberately – features that compromise or destroy aspects such as security
- We cannot examine how they achieve their functionality; we cannot, for example, apply techniques such as static code analysis when assessing their role in a safety-critical context

In practice, some component suppliers may be willing to provide internal details, although especially where national boundaries are crossed, this may require some negotiation.

System Acquisition and Support. The impact of COTS on acquisition can be seen most clearly in Table 1 that compares the "traditional” approach, in which the customer (say, NATO) fully specified all system components, to a COTS-based procurement.

TRADITIONAL	COTS-BASED
NATO able to plan and control system development	COTS components change asynchronously and rapidly
NATO able to define functionality	COTS supplier defines functionality to suit larger market. NATO spec may preclude use of COTS if too rigid.
NATO able to control/view development process to support its responsibilities for certification, etc	COTS item is "black box" and alternative approaches to certification, etc may be needed
NATO able to control interfaces and interoperability	Interoperability may be enhanced if same COTS component in both systems, but otherwise may be very difficult because COTS interfaces not fully defined/maintained
NATO able to exploit expertise, standards, etc for component engineering	Key activity now becomes systems integration – more of a "black art"
NATO able to control functionality	COTS supplier may define upgrade package (eg operating system plus applications)
NATO able to co-ordinate change to component with change to whole system	COTS component change driven purely by commercial factors, not synchronised with system constraints (eg refits). May lead to many variants of equipment fit across fleet of platforms.
NATO able to procure changes/fix problems, especially in emergency, perhaps in the field	COTS component changed if and when supplier sees market advantage; NATO not a significant customer
NATO able to assume component will remain available (especially components that wear out)	COTS component may simply cease to be available (not just be unsupported) if commercial market moves away from it

Table 1 Traditional v COTS-Based Acquisition

Fundamental characteristics of COTS items that might be exploited in NATO systems can thus be summarised – perhaps rather starkly – as:

- "Take it or leave it" functionality
- Rapid change
- Out of NATO control

COTS Software. There are thus two key issues that apply to all COTS items but which are especially problematical for COTS software.

The first is *control*. A major advantage of bespoke components is that the customer can control the functionality, interfaces, schedule, upgrade path, etc. Conversely, with COTS items, the customer is not the leader but the led. By its nature, COTS software is subject to much more variation in functionality and interfaces than a relatively constrained item such as a processor chip.

The second issue is *visibility*. Bespoke software can be examined to ensure it does not include any feature to prejudice security, safety, etc. In contrast, most COTS items are "black box". It is generally accepted these days that obscurity is not the same as security and that on balance, the interests of security are best served by transparency. Again, visibility is an issue that is particularly relevant for software since software is generally much more complex and flexible that hardware.

Within the field of COTS software, the operating system (OS) is especially key. It is central to the whole capability implemented in software and can be very complex. It also pivotal in the sense that very often a change to the OS for whatever reason can mean a change to the applications running on it. This is particularly troublesome if, for example, a change of OS is needed to fix a bug and this solution only comes as a package that introduces new problems, in the shape of revised applications.

It is interesting to note that in this way, a change to the COTS OS can make the applications that run on it obsolete. That is, the COTS system element can actually make proprietary system

elements obsolete - a perhaps unexpected situation. Of course, this usually arises where the OS is COTS, but is also itself proprietary and single-source.

Note that in this paper, the emphasis is on general purpose operating systems rather than more specialist examples, such as real-time operating systems for embedded processors.

Addressing the Problems. The capability impact addressed above - eg where a potential enemy has the same capability as ourselves through using the same COTS item - requires that we undertake a much broader review of issues. Major changes in strategy may be driven by answers to questions such as:

- Where does our COTS-based system have the edge over an enemy's system that uses the same COTS items?
- Where are the weaknesses in our system that the COTS items introduce? How might an enemy exploit these? What countermeasures can we put into place?
- If we have to conclude that our COTS-based system does not offer significant, dependable superiority of technology, is there some other source of military advantage for us, such as superiority of training or numbers?

The systems design issues - when we no longer have visibility of the internal behaviour of the COTS item - implies that we have to consider means of containing any undesirable behaviour and preventing it impacting on the rest of the system. Such approaches often take the form of "wrapping" of some kind, but introducing parallel COTS components from different sources and using voting may be an alternative in some circumstances.

Also key for system design is the question of standards. COTS components are usually associated with standards of various kinds. These standards may address the interfaces/ interoperability of the item and/or its functionality. Standards may be *de jure*, typically endorsed by an international standards body or broad-based industry group, or *de facto*, typically set by a single, dominant supplier.

In either case, the choice of standard during development is crucial. Important questions include:

- How stable is the standard?
- How definitive is it? (eg can widely-differing items both claim compliance?)
- How many vendors/products support the standard now?
- How many will support it in the future?
- Is any replacement standard likely to offer upwards compatibility?

Of course, standards are most important from an obsolescence viewpoint if the strategy is to use them to define a "hole" in the system into which can be "plugged" a variety of products from a variety of suppliers, all of which "fit". This is one approach, but in some areas, others are also possible.

The Best of Both Worlds? As noted above, the key issues for "traditional" COTS software are control and visibility. These are the characteristics that have to be traded off against the advantages offered by a COTS item. However, one class of software component does appear to offer the best of the bespoke and COTS worlds: open source software.

Open source software is freely available to all interested parties. It may be copied, changed and distributed onwards. Thus to all intents and purposes, it can be owned in the same way as bespoke software. However, it may not be totally without restriction. For example, usually it *is* licensed and the licence stipulates that if it is changed then the modified version cannot be redistributed unless it too is freely available.

Open source software (OSS) therefore offers the control and visibility of bespoke software while at the same time avoiding the cost and risk of developing the software from scratch.

Furthermore, the OSS items tend to be exploited and modified by a wide community of users across the globe, communicating via the Internet. The OSS item is thus essentially "owned" by a wide community of enthusiastic people who want to see it succeed. Because the source is available to them, they are able to identify problems by analysing the code rather than simply waiting until some erroneous behaviour is spotted. They are also able – and motivated – to devise solutions and disseminate these to others.

This cultural dimension of OSS is a very significant factor in its success.

Linux. The best known example of OSS is undoubtedly Linux. It is important to note that some of the ways Linux has developed and its current position are not necessarily typical of other OSS items, and OSS components do not necessarily have to follow the Linux model. However, Linux is so significant that it deserves attention.

Strictly, Linux is an operating system consisting of the kernel (that provides the basic mechanisms for scheduling, etc) and device drivers that allow

it to communicate with various peripherals. However, in practice, the term is also used to apply to a wider collection of items, including, for example, a graphical user interface.

The strict interpretation is useful to bear in mind since while the kernel is essentially standardised (see below), there are a number of different options – virtually all open source themselves – that exist for the applications that go with the kernel to make it an "operating system" in the Microsoft Windows sense – ie the kernel plus a whole host of other things that actually allow the user to do something useful. Thus the various Linux packages ("distributions") that are available from a variety of suppliers all provide a different set of items together with the standard Linux core.

The Linux kernel is essentially controlled by the originator of Linux, Linus Torvalds. Typically, somebody in the world will identify the need for a new feature and publish a very early and imperfect version of it. Others will use and refine this, also publishing their work. Eventually, the item will become stable and widely used and then accepted into the "official" version by Torvalds.

There are several implications of this, of course. On the positive side, it is very visible in which way the product is moving and interested parties can at the very least monitor this. They can also influence it if they are prepared to actually contribute development effort. The disadvantage is that in fact it may be moving in conflicting directions (eg there are currently a number of different hard real-time extensions being developed) and the final outcome might not be at all clear.

There is also an obvious issue over the role of Torvalds as the arbiter of what constitutes a formal release of Linux. His role is vital in deciding when a new release occurs and what it contains, and as the system grows this becomes ever more demanding. Already, there are some indications that releases are slipping behind schedule (eg version 2.4). There is also some uncertainty about what will happen when Torvalds, for whatever reason, relinquishes this role.

Technically, Linux is a flavour of Unix, although it is worth noting that it does not fully comply with the Open Group's criteria that would allow it to use the Unix trademark. Partly due to the way it has been developed, it is very modular and has a relatively low number of system interfaces when compared to Windows, for example (230 rather than 3500).

A key feature is that Linux has been implemented on a very wide range of machines. This is facilitated by its modularity and relative simplicity, making it possible to run it on "bottom end" architectures.

Other (Open Source) Software. The same basic approach to development that has proved so popular for Linux has been adopted for many other pieces of software, although a lot have followed a more traditional, and some would say more controlled, development process. Not surprisingly, most other OSS items are designed to run on Linux and many provide the functionality that users have come to see as essential, eg a graphical user interface.

Literally thousands of open source developments are under way, although these vary immensely in what they offer to typical end-users (as opposed to computer systems engineers, for example) and there is much duplication.

Office software, some open source, and other applications such as databases (eg from Oracle) are available to run on Linux. One particularly outstanding example of an open source application is the Apache web server software and some estimates give Apache and Linux respectively a 60% and 30% share of all web servers on the Internet. Products such as WINE allow Windows applications to run on Linux.

Despite all these initiatives, though, the current situation is that Linux has a far less rich set of applications available for it than has Windows. However, in the field of palmtops and similar devices, where the processing power is relatively limited and unit costs for the operating system are significant, Linux may easily gain the edge.

Linux and Obsolescence. Linux offers some significant advantages when combating obsolescence, but also raises some issues.

Advantages. As noted above, the operating system is a crucial element of the system when considering obsolescence. Because it is open source, Linux has some vital advantages over a commercial, closed source OS:

- Changes for bug fixes etc can be made in whatever way is appropriate, eg to retain the same interfaces for applications so that they do not need to change
- Hardware can be added or changed relatively easily since the drivers are readily accessible, and porting can be undertaken
- Changes to accommodate new requirements can be made as needed

Of course, these benefits arise simply because we have access to the source code, with all that gives in terms of visibility and control. In addition,

there are advantages that come from the “Linux culture”:

- Others may have already developed and published a solution to the obsolescence problem
- If not, it may be possible to reduce cost and timescales by collaborating with others who share the problem
- A major element in combating obsolescence is having a plan for how future versions of the system will change to meet future needs, and there is great visibility of future Linux developments

Thus both the availability of the source and the broad development model of Linux offer many advantages. Naturally, though, there are some issues to be addressed.

Issues. If a customer, eg NATO or one of its member Ministries of Defence, decides using Linux in its systems is desirable, specifying this for a supplier is not trivial. Because of its modular nature and the wide variety of “distributions” available, a comprehensive list of modules, applications, etc is needed rather than a simple specification like “Windows NT version 4”.

Much more significant is the question of how Linux might be exploited across a range of systems. Because of its portability and scalability, Linux lends itself to being used on many hardware architectures and there are obvious advantages in adopting it as a common platform. As well as countering obsolescence in the ways already discussed, this would also increase opportunities for re-use.

However, once we have a range of systems all using Linux, how do we manage the problem of upgrades, bug fixes, etc? A whole spectrum of options exist. We can simply highlight the problem and wait for the Linux community to solve it. This is directly analogous to the position with Microsoft and Windows. At the other extreme, we can actually make the change ourselves. We can also collaborate with other interested parties. In practice, it may be necessary to adopt a mixture of approaches, depending on individual circumstances.

A key question for defence systems with their typically long lives is: how long will the Linux community exist as it does now? Answering this requires predicting the future, of course, and so cannot be definitive, but the author’s views are as follows.

Since the early 1990’s the Linux community has grown rapidly to a size now of around 10 million. It is clear from looking at the various related web sites that there is a strong element of enthusiasm for the technical strengths of Linux, a major academic involvement, and a hint of religious wars against Microsoft and closed source software (not necessary all at the same time!). There are also echoes, for those old enough to remember, of the “Unix is about to rule the world” messages that have been appearing periodically over the last 25 years or so. Thus while the popularity of Linux is still growing, there is always the risk of something new catching the community’s imagination as time passes.

Linux will never achieve the total market penetration of Windows, which despite its failings will remain the dominant operating system for desktops at least. Issues such as backwards compatibility and migration paths will be of less concern to the Linux community than to Microsoft (although the Microsoft route may not be easy and the “do it yourself” option is always available for Linux).

Thus while Linux will not disappear altogether, it seems very unlikely that in 20 years’ time – perhaps even 10 – the community will exist as it does now. In many ways, Linux will then itself be obsolete! Given the cultural environment in which Linux has flourished, it may even be that visible exploitation by the defence community might hasten this shrinking of global support.

This does not, of course, mean that the defence world should dismiss Linux. What it does mean, though, is that if it is to adopt it widely, it must address this long-term issue.

A separate issue is related to the special defence needs of considering security, safety, etc. In principle, the answer is easy because all the Linux source is visible. In practice, although Linux is relatively simple compared with other operating systems, understanding adequately how it behaves is not easy.

More generally, even while a large Linux community exists, it can only be relied upon to provide some change if that modification has broad enough appeal. If the defence world is likely to need some more arcane work done (eg interfacing to a specialist device) – especially if it is urgent – then it is likely to be in the position of needing to be capable of doing it itself.

Finally, but by no means least important, is the question of verification and validation and confidence that the rather special way in which Linux is developed, released and controlled can provide a product that is suitably robust.

Again, the fact that the source is available, there is a large community of interest and Linux is relatively simple all help to suggest that at least if

a problem is found, it will be relatively easy to overcome. Neither, despite the impression its background might form in some minds, is it really obvious that Linux starts off any more likely to be faulty than a commercial OS. Nevertheless, this remains an issue to be addressed.

A Solution.

If the advantages of Linux are to be exploited, one way forward is to establish a "Linux Centre" for the domain of interest, eg the UK MOD or NATO. This Linux Centre could then act as the focus for Linux use across a number of systems in the customer's domain, see Figure 1.

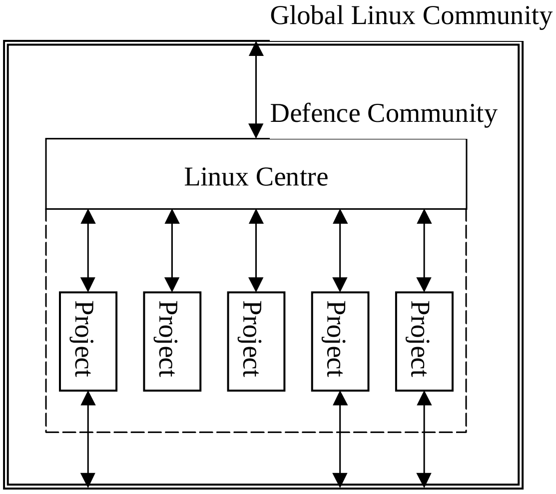

Figure 1 The Linux Centre

In particular the Linux Centre could:

- Be the repository for knowledge especially relevant to the domain (eg on security/safety issues)
- Offer the skill base necessary to make changes that for one reason or another cannot come from elsewhere
- Provide additional verification and validation functions to increase confidence in the Linux versions used
- Ensure commonality to whatever extent is appropriate, eg by defining the "standard" Linux distribution
- Synchronise upgrades, etc so that commonality is maintained
- Retain knowledge of older versions where appropriate
- Act as a clearinghouse for proposed changes to Linux: providing synchronisation across projects within the domain, supporting synergy between activities on separate projects, etc
- Act as an interface to the wider Linux community
- Retain knowledge, skills, etc as and when the larger community contracts

In essence, therefore, the Linux Centre would be a mirror within the specific defence community of the broader Internet foci that exist, such as Torvalds and various Internet sites. It would enable this broader community to be exploited, but reduce dependency on it.

Within the domain of defence systems, it would be important that the open source culture survived as far as possible, with projects interacting within themselves and more widely to produce rapid and collaborative solutions. However, the extra focus, synchronisation and longevity of the Linux Centre would ensure maximum benefit across the defence enterprise.

There are many options for the organisational form of the Linux Centre. Some of the aspects related to safety, for example, might be common with many non-defence domains, so sharing could take place. Also, support is commercially available now from a number of companies and it may be that some at least of these companies continue to offer support as the general community declines.

A Linux Centre is not without its own difficulties. As noted above, its mere existence may diminish the global support for Linux and thus undermine a key reason for using Linux in the first place!

Even an open source approach just within a limited defence community (eg on a national basis) raises issues of multi-project, multi-organisation working that would require a major re-think of some traditional attitudes in both procuring and supplying organisations.

There is also a question over balancing the open source culture of rapid "try it and see" refinement through collaboration with more traditional needs, practices and attitudes that tend to reflect increased levels of control.

However, widespread adoption of Linux without addressing these sort of issues entails a risk of being hit by what is essentially the obsolescence of Linux, with a much greater impact than if one had stayed with Microsoft!

The Open Source Future. Will the trend towards open source software in areas other than the operating system continue? Probably yes.

Operating systems are at the bottom of the OS/applications/service hierarchy of possible products vendor organisations might offer. Operating systems are no longer a major value

item for vendor or customer, and it is perhaps not surprising that the first real open source success is Linux. As the focus shifts more and more up the hierarchy, then the more likelihood there is of the levels that are “left behind” becoming open source as their value reduces:

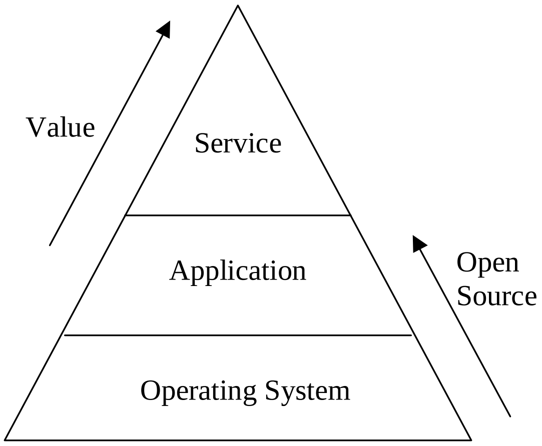

Figure 2 Open Source Evolution

On the other hand, the open source development model only has maximum value where there is a large community of interest who are enthusiastic to participate. As one climbs the hierarchy, there is an inevitable narrowing of interest as specialism increases. Another factor is the relative level of involvement of the academic community, which may be different for operating systems and word processors, say.

On balance, though, open source items seem likely to be a significant feature of the software world for some time.

Conclusion.

COTS items do offer major advantages in combating obsolescence, but their use does introduce other issues that must be addressed in a variety of ways.

The advantages are reduced if the COTS item is single-source and black box. In these circumstances, the vital aspects of visibility and control are severely weakened, if not lost altogether. Unfortunately, the operating system is one key system element that typically does have these undesirable attributes.

Linux, as an open source operating system with a very active user/developer community, offers much of the best of both worlds. It does not have to be developed from scratch, yet can be as visible and under control as a bespoke item. Also, it has already been ported to many hardware architectures, offering the possibility of a standard platform across a whole range of systems, with attendant opportunities for re-use, etc. Similarly, it offers the prospect of relatively easy porting to new architectures in the future.

However, Linux provides a much less rich set of applications than Windows and this seems likely to remain the case. In addition, the wide community of interest that has driven its success so far may well not be sustained over the long term. Even in the short term, the community addresses problems that are of interest and value to itself, and these may not coincide with defence system needs.

Thus while adoption of Linux is undoubtedly an attractive prospect in some ways, its widespread use introduces a number of issues. One way to address these is the establishment of a Linux Centre that can be a focus for defence needs and provide some degree of dedicated capability while still exploiting the broader community.

In addition, if the open source culture of rapid development and collaboration is to be retained, some change in approach from procurer and suppliers will be required.

More generally, the open source model is likely to spread, although its extent is difficult to predict. On balance, open source software provides a major opportunity to address at least some aspects of obsolescence. It should be exploited, but will require steps like those proposed for Linux to gain its full potential.

An Integrated Approach
to
Reduced Total Ownership Costs of Aircraft (RTOC)

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Summary

The Reduced Total Cost of Ownership (RTOC) Study was a unique, "out-of-the-box", integrated Science & Technology (New Processes & Techniques) approach to obtaining more affordable aircraft weapon systems and modernizing these systems for future combat scenarios. The RTOC Study stands in contrast to the individual "bits & pieces" technology transition plans seen in the past. Individual plans can result in costly programs that are hard to justify and are easily attacked when evaluating fiscal parameters. An integrated Reduced Total Ownership Cost (RTOC) approach, with substantiation data provided by the proposed follow-on effort, would be easily justified by these same fiscal parameters using this new cost database.

Background

Affordability has become the number one issue to today's military planners. This affordability thrust, however, is slightly different than those of the past. This time this thrust is being driven out of "need". As stated in Figure 1, today forty-one percent (41%) of the United States Air Force (USAF) total inventory is over 24 years old. By the year 2005, seventy-five percent (75%) of the total inventory will be over 20 years old. The B-52 and KC-135 will be approaching 60 and 80 years of duty, respectively, at their currently planned retirement dates. The cost of sustaining this aging inventory as a viable military force continues to increase for several reasons: economic obsolescence, high operations tempo, aging of aircraft subsystems, new operational techniques, and a reduction in experience level of the maintainer just to mention a few. While solutions are available to maintain these weapon systems as viable 21st Century vehicles, in most cases, the non-recurring cost is prohibitive. The funding for these upgrades must compete with basic fleet maintenance and other modernization activities.

In those cases where technology insertion has been implemented, it usually has been by individual subsystem upgrades, a "bits & pieces" approach. While such an approach can meet key operational needs and reduce subsystem maintenance, the stand-alone upgrade bears the entire development and implementation costs by itself. Additionally, stand-alone upgrades, while improving Reliability & Maintainability (R&M) of individual system, may not impact the total weapon system R&M performance. If the integrated weapon system R&M performance is not improved, the weapon system will experience a lower operational readiness and potentially a reduced combat effectiveness. This could be labeled as an

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“unbalanced” O&S design. The benefits of technology insertion can be lost if the cost of implementation is considered “too high for the benefits achieved”. Arriving at a realistic “business case” for implementation of a given technology is as important as developing the technology itself. In the case of many technologies, however, it may be that traditional estimating models do not adequately account for the technical and/or process benefits afforded or the current database is inadequate to predict the cost and/or the savings. The “bits & pieces” upgrade philosophy, coupled with tightly constrained budgets, have precluded the ability to create the data required for establishing an integrated cost model for new technology.

Study Objectives/ Requirements

The RTOC Study had the following major objectives. The first major objective was to validate that technology can reduce the life cycle cost of an aircraft by 40 to 60 percent. The baseline aircraft for this study was an existing aircraft that has an extensive cost database and weight and volume trade space for meaningful R&M studies. The study’s focus was on acquisition, RDT&E, and O&S cost savings. The current Air National Guard operations tempo and basing was used to formulate cost comparisons.

The second objective focused on critical aircraft design and assembly processes with the idea of “Revolutionizing the Aircraft Industry”. Critical design and assembly processes necessary to achieve the full benefit of the new technologies must be identified and/or defined. These processes support the elimination of Programmed Depot Maintenance (PDM), provide efficient growth in aircraft systems, utilize the new cost implementation models, reduce the cost sensitivity to production rates/line breaks, and achieve sustainable high levels of R&M over the life cycle of the weapon system

Two key requirements for the RTOC Study were (1) the primary mission would be air-to-air, and (2) the current mission performance could not be reduced. The configuration defined during the study met these criteria, but possessed a robust air-to-ground potential and a significant mission growth capability. This configuration also allows for an easy conversion to a two-seat variant for future growth and flexibility to accommodate future technology demonstration tasks.

Figures 2&3 show the problem in historical terms. We are all used to the cost estimating relationships being expressed as log-log curves as shown in figure 2. The problem with using these curves is that we have lost not only the historical data on them but also we do not know how these curves have been impacted by the need for obtaining the utmost in performance at any cost. This chart graphically shows the problem. We are very comfortable in estimating cost between the top two lines. But technology demonstration programs have shown that we can get down to the lower line. The problem is getting the cost community to accept this as the current state of the art. The cost community includes everyone in that process from the initial engineering estimate to the final cost that we see in the formal proposal.

The second area where cost estimating relationships are not able to capture the impact of technology is the learning curve as shown in figure 3. This chart is another example of the cost-estimating dilemma. This is a learning curve. It is used to adjust the historical data over the projected buy and the efficiency introduced when you build the same thing over and over again. Where you draw this curve makes a big impact on the cost of you first articles and total program costs. Today’s technologies are driving this curve to a nearly straight horizontal line. This says that costs could be independent of quantity buys. That is the first article costs as much to build as the last article. This is a significant impact on program costs and says that in the extreme you could be independent of production line break, as there is little learning curve to retain. With virtual reality, we are now able to build and assemble a large structure many times in the computer and with the latest technology we are now close to making this curve essentially a horizontal line.

Technology Maturity

One important factor to be considered in a study of this kind is to ensure that any proposed technology has an appropriate maturity in order to manage risk and avoid cost overruns. One tool for assessing this is known as Technology Readiness Level (TRL), see Figure 4. The TRL goes from a value of 1 for a basic idea through a defined range up to a value of 9 for something in 'operational use'. These values must be qualified in more detail depending on various factors. If the technology, or component, is in operational use on a different military aircraft system then there is little question about the TRL. Only the integration issues, or changes required, need to be analyzed for a credible assessment to be made. On the other hand,

Commercial Off The Shelf (COTS) equipment is popularly considered to be a potential cost saver for military applications. Something that is in routine commercial use may still need qualifying for different environmental factors. It is also possible that it can be decided that there is no significant difference and a TRL of 8 can be assumed for application. One factor that will have a strong influence on the analysis is whether the technology under consideration is considered flight safety critical, or mission critical, or less critical. Obviously, flight safety critical items will receive the closest scrutiny. We can consider the flight control system to be in this category and will be discussed as an example.

The F-15is a good illustration of the process because it has a mechanical flight control system that is a significant maintenance item. New high-performance fighters are designed with digital control systems for reasons of cost and performance, and such a change must be a consideration for the study. There is no COTS possibility, the military are ahead of all commercial applications in this area because of the flight envelope and maneuverability requirements. Replacing the mechanical system with a new design would be a significant development effort. In order to avoid the cost of developing a new FCS, we must look at other possibilities. In terms of a system in operational use (to maximize the TRL), we might consider the F/A-18E/F. While there would be many similarities, the control laws for carrier landing would certainly need to be modified for USAF operation. Next we can consider a control system that has flown in research programs. Both the STOL & Maneuver Technology Demonstration (S/MTD) program and the Advanced Control Technology for Integrated Vehicles (ACTIVE) program have used an F-15 to conduct thrust vectoring research programs. The S/MTD flight control system was designed with a new digital control system with no dissimilar backup and first flew in 1988. A primary objective of the program was to integrate thrust reversing and pitch vectoring into an integrated Flight/Propulsion Control system. The control system also included a reversionary mode that did not use any of the propulsive control components as a reference for the other research control modes. Referred to as the CONVENTIONAL mode, it enabled the aircraft to fly and feel to the pilot like a normal F-15 but with subtle improvements. After the S/MTD program finished, the same testbed was modified to incorporate pitch/yaw vectoring nozzles for the ACTIVE program. The same CONVENTIONAL mode was retained and flight testing has continued to this date. This hardware could be considered to be at a TRL of 8, i.e. flight qualified through test and demonstration. The control laws and software of the mode might be considered at a TRL of 7, although it has been operating successfully for twelve years it has not been cleared for unrestricted flight throughout the F-15 envelope.

The preceding discussion is intended as an example of a process that can be used to help in ranking competing technologies or alternatives. It is intended to reduce some of the subjectivity in assessing the readiness of technologies, both hardware and software, for application in a production system.

Study Results

The study duration was nine months and the deliverables included the definition of:

(1) A reference aircraft configuration that would reduce Total Ownership Cost,

(2) The identification of new, robust design and assembly procedures that when implemented would incorporate new technologies and processes.

(3) Identification of new maintenance and supply concepts that reduce the Life Cycle Costs.

Because the study was only nine months long, we concentrated on the life cycle elements highlighted in figure 5. This is significant in that later on in the paper you will see substantial savings and you must remember that we not only did not address all aspects of life cycle costs but also we did not study everything to the same depth. So the results we show at the end of this paper are very conservative.

After establishing and zero basing the baseline production configuration, the air-to-air superiority production baseline was established. Sixty-three (63) trade studies were defined that offered the potential to reduce the total ownership cost and/or to provide essential 21st Century aircraft system capability. The 63 trade studies and numerous S&T program opportunities resulted from numerous, joint brainstorming sessions with numerous technology experts. Following an iterative process of analyses and review, the findings of 47 trade studies were approved for the study aircraft. Another 6 were selected as options for future consideration (Fig 6), and the remaining 11 were not approved. The production baseline modified by the 47 approved trade studies is the final configuration for the study. This configuration was used for O&S and acquisition cost comparisons with the baseline configuration.

We will now show a few examples of the results of the trade studies.

Design / Manufacturing Processes

As part of the study, a new, robust aircraft design and assembly process provide a flexible, most cost effective process for building, modifying, supporting, and maintaining the study aircraft over its 20 year life cycle. (Fig 7)

The robust, flexible, design and assembly process to be utilized for the study aircraft combines three-dimensional computer aided engineering/re-engineering of the current design coupled with selected applications of Design for Manufacture and Assembly (DFMA). DFMA adds to the 3D computer aided design tools, the introduction of more durable materials, improved designs, automated manufacturing processes, and affordable tooling. During the Phase I Study in-depth technical and cost analyses of the application of these modern methodologies to the current production baseline design were accomplished. The results of these analyses determined that 3D computer re-engineering would be applied to all areas of the design. DFMA techniques would be used for a redesign of the forward fuselage, the wings, and selectively applied in the empenage and center fuselage areas of the fighter. The most direct affect of these new processes is a large reduction in fabrication and assembly hours and the corresponding cost savings.

A major benefit of the computer-based design is the flexibility to manufacture major aircraft structure at the most cost effective location, and then be able to mate the structural sections from the various locations with minimum design refinements. Thus, 3D re-engineering combines improved design and assembly processes with the lowest cost manufacturer.

In addition to the above benefits, several avionics and subsystem upgrades can be directly incorporated into the 3D re-engineering and DFMA design processes. This inclusion of the avionics/subsystem upgrades can significantly reduce the aircraft (non-recurring) costs of implementing lower cost avionics/subsystem enhancements. The computer basis of the design will continue to make future growth driven upgrades more efficient, and have a positive impact on maintenance training and line maintainer efficiency. It also couples with the use of electronic technical orders.

An example of the benefit of this technology on parts count and assembly is shown on figures 8 & 9 but the problem of incorporating this technology in cost estimating is also shown. When the cost estimating was accomplished using historical methods for 115 units, the estimated cost of these assemblies were predicted to increase even though there was approximately a 50% parts count reduction. This is because the models are weight based and we allowed the weight to increase if it simplified a fabrication or build problem. The delta’s in the cost estimates highlight the uncertainty in the estimating techniques even for simple structure.

Effect on Maintainability

A significant part of achieving RTOC savings is improved Reliability and Maintainability (Fig 10). The study aircraft configuration provides significant improvement in R&M versus the baseline. These improvements are across all major subsystems within the aircraft. This is very significant. Not only does this reduce the overall unscheduled maintenance man-hours of the aircraft by approximately 70%, but by balancing the improvement across all areas ensures an overall system impact. The steeper slope maintenance man-hours for the different subsystems indicates the criticality of certain key “bad actors” to overall weapon system performance. If not addressed for any reason, a single subsystem can drive the total aircraft maintenance requirements. Figure 11 shows what the maintainer of the near future could be. With electronic maintenance instructions interwoven with 3 dimensional solid models, the maintainer has not only everything he needs to accomplish the required maintenance action, but also to train in virtual reality while the aircraft is returning to base with the known maintenance squawks.

Coupled with the improved R&M, the aircraft configuration possesses features that will provide significant assistance to the aircraft maintainer. The Organizational to Original Equipment Manufacturer (O-to-OEM) maintenance concept can greatly simplify flight maintenance by providing a “remove and replace” approach. The O-to-OEM approach is facilitated by highly reliable equipment with improved diagnostics. The Vehicle Management System is a key example of the improved diagnostics available within the 21st Century configuration. Finally, the use of new generation of electronic technical orders (Interactive

Electronic Technical Manuals - IETMs) will provide more available, more explicit support of the flight line maintainer both at home and when deployed. The improved R&M, a balanced O&S design, elimination of PDM, and next generation aids for the maintainer combine to have a significant impact on Total Cost of Ownership. This combination also reduces the impact of lower maintainer experience levels currently experienced in the fleet.

Deployment Footprint

We did a small study on deployment footprint and got significant results that will cause us to look at this area in the next phase. By adding an APU to the configuration, we were able to reduce the deployment requirements for airlift. Figure 12 shows the reduction in airlift requirements by adding an APU to the airplane so it could be maintained away from main operating bases with a reduction in ground support equipment

Final Results

From the study, we were able to potentially reduce the acquisition costs by 40-60%; the O&S costs by 40-70%; and direct personnel support by 25-55%. Remember that with these results, we did not address the total Life Cycle Costs so there are more opportunities for cost reduction than what is presented in this paper. Along the way, we started talking about an aircraft that has a scheduled inspection cycle of 100,000 miles or 5 years. Although starting as a joke, it did start people thinking “out of the box” and we have new ideas to explore for future reductions in cost of ownership.

The study showed the necessity of obtaining new certified cost metrics so that everyone understands the impact of technology on historical cost estimating relationships. Also we think this process will revolutionize the aircraft industry and the Air Forces of the world.

Summary

The RTOC configuration achieved all the objectives of the study, and met a large majority of the USAF defined future requirements. The integration of new technology, flexible acquisition systems, and advance processes can reduce the cost of ownership of all aerospace systems. But these technologies/ processes can only be implemented after the data is gathered so that the business cases can be made to use the technologies.

AFFORDABILITY ISSUES

- Most of Today’s Inventory are Legacy Weapon Systems
  - Today: 41% >24 Years Old
  - In 2005: 75% >20 Years Old
- Sustainment Cost of Legacy Systems Continue to Increase
- Limited Funds Exist for New Technology Insertion
- Business Cases for New Technology Insertion and Processes Rely on Accurate Costs / Savings Databases
- Low Credibility for Savings that Result from New Technology
  - “Bits & Pieces” Approach Not Cost Efficient
  - Little Data Exists to Create Cost Models Deltas
  - Weight Based or Part Count Models Not Always Valid
- **CAIG’s Not Accepting Technology Cost Benefits**
  - Future Weapon Systems Incorporating New Technology May Not Benefit

Inability of Current System to Estimate Cost/Savings of New Technology/ Process Improvements

Figure 1

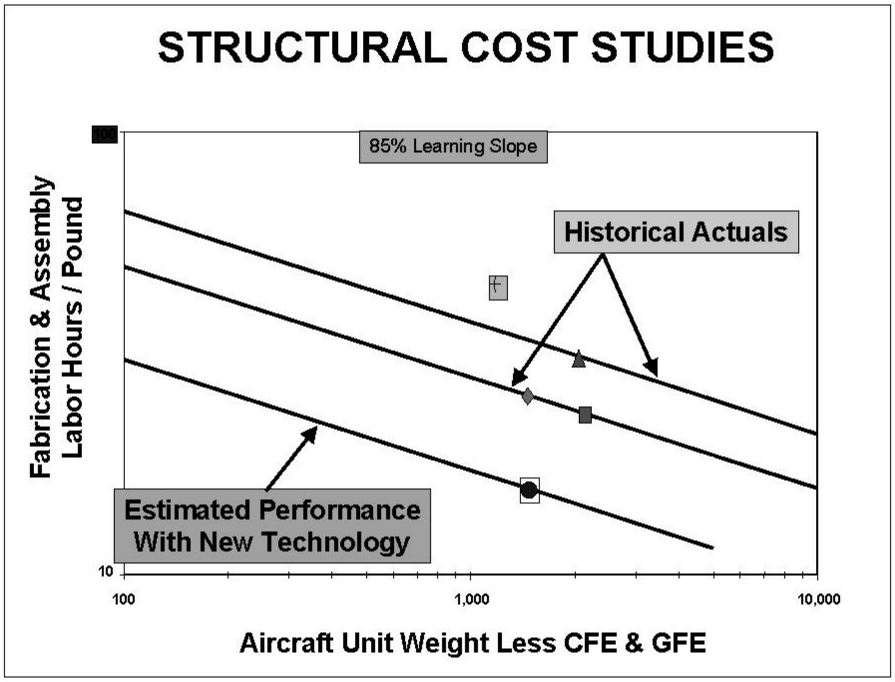

Figure 2

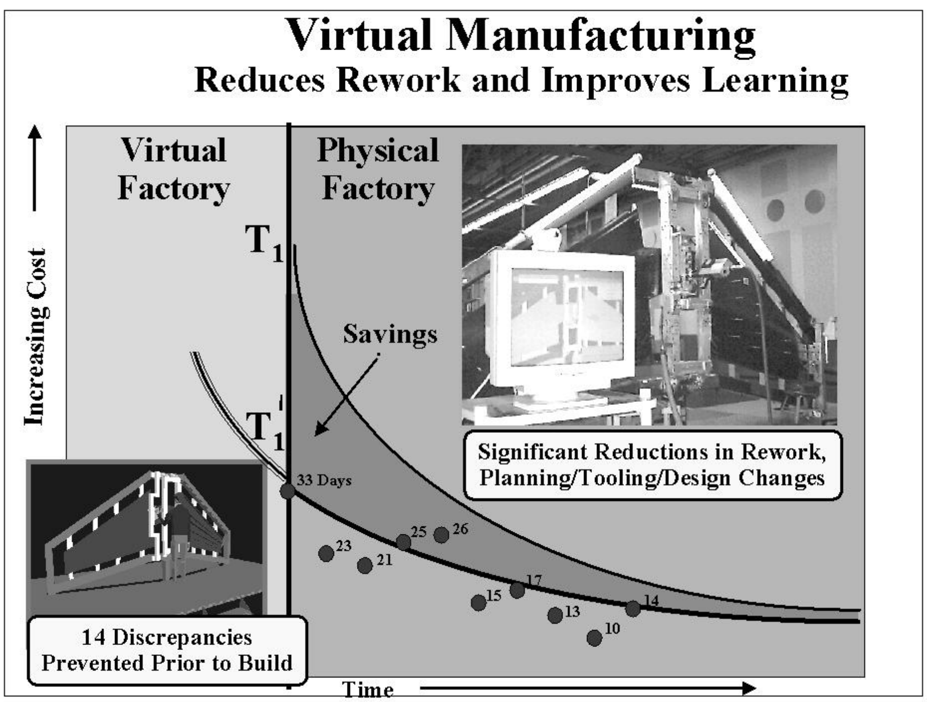

Figure 3

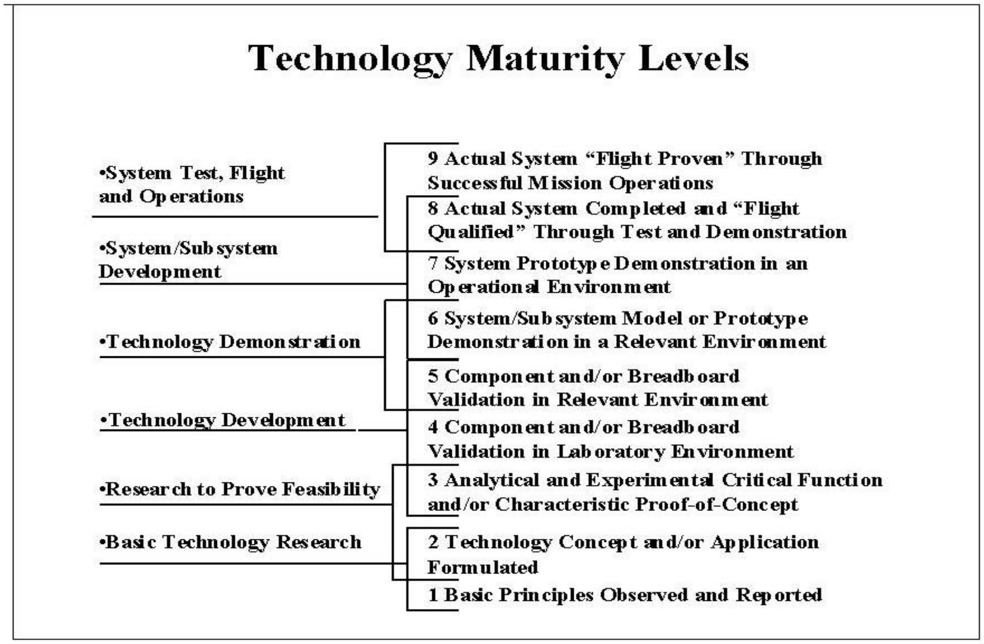

Figure 4

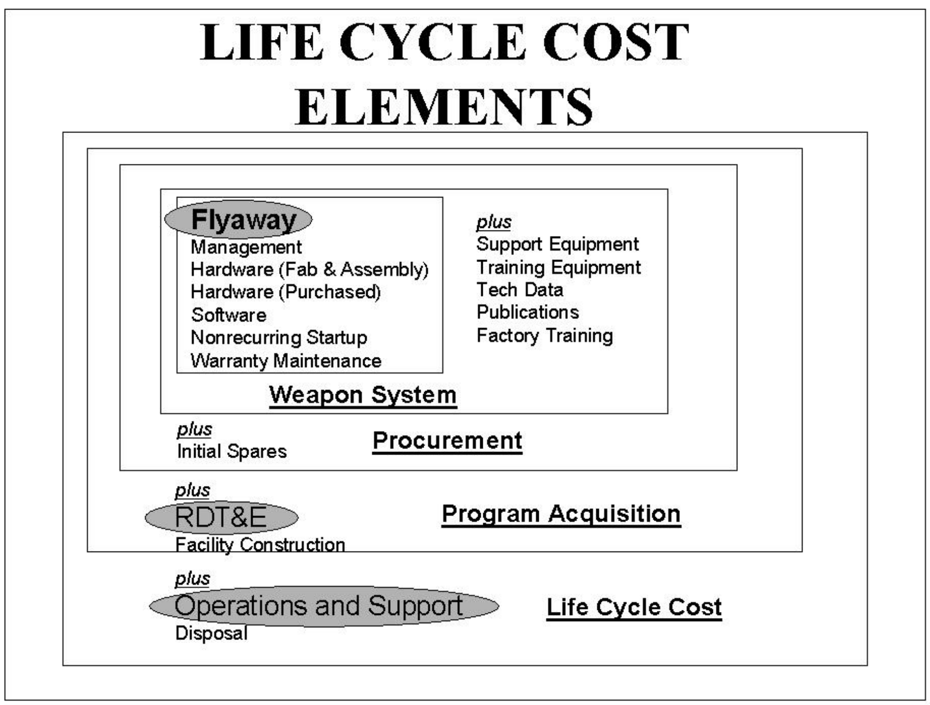

Figure 5

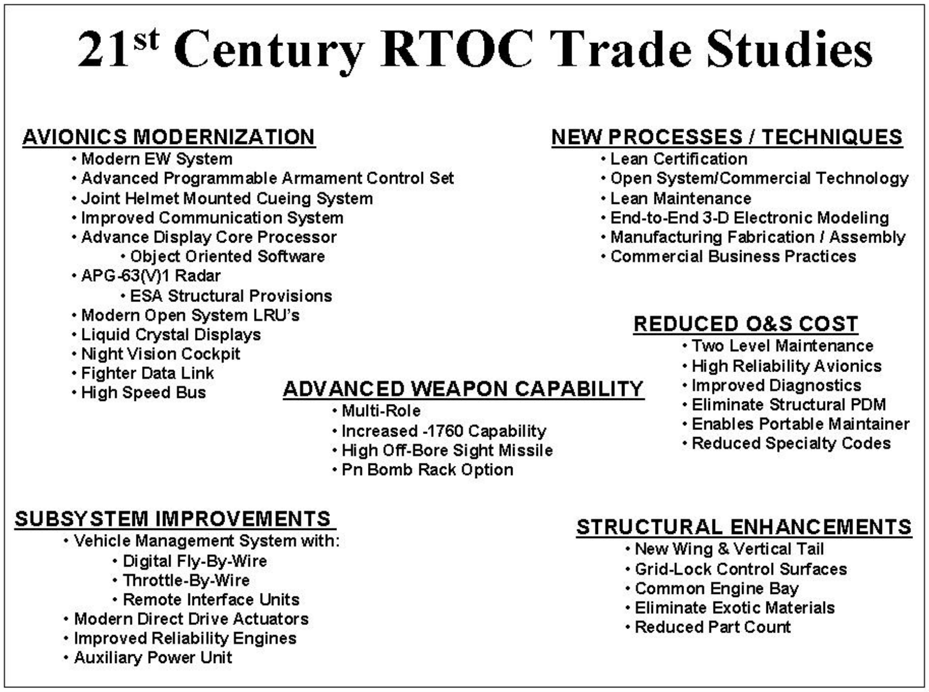

Figure 6

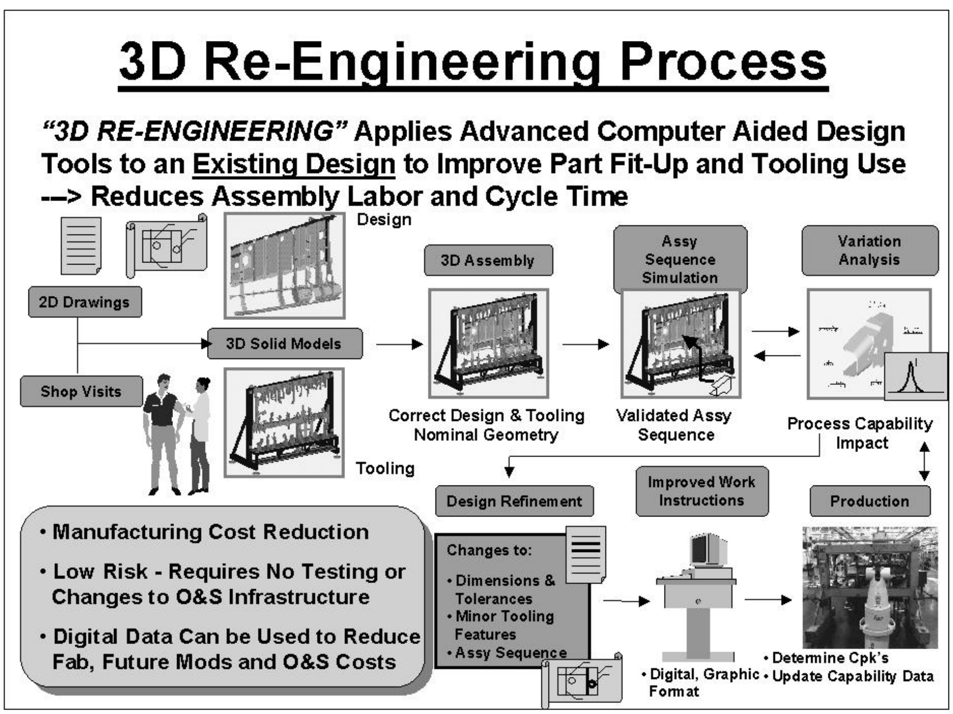

Figure 7

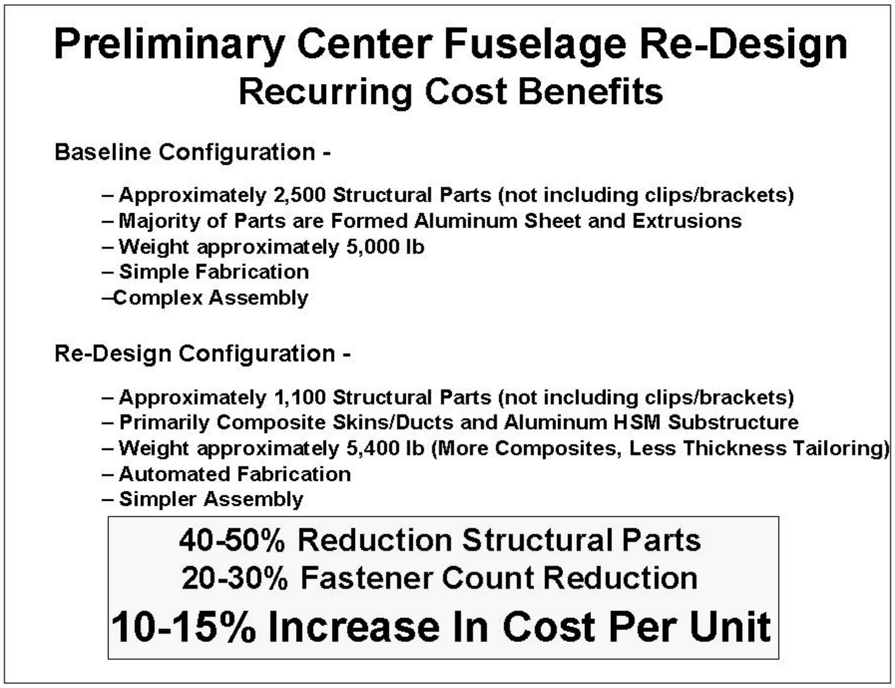

Figure 8

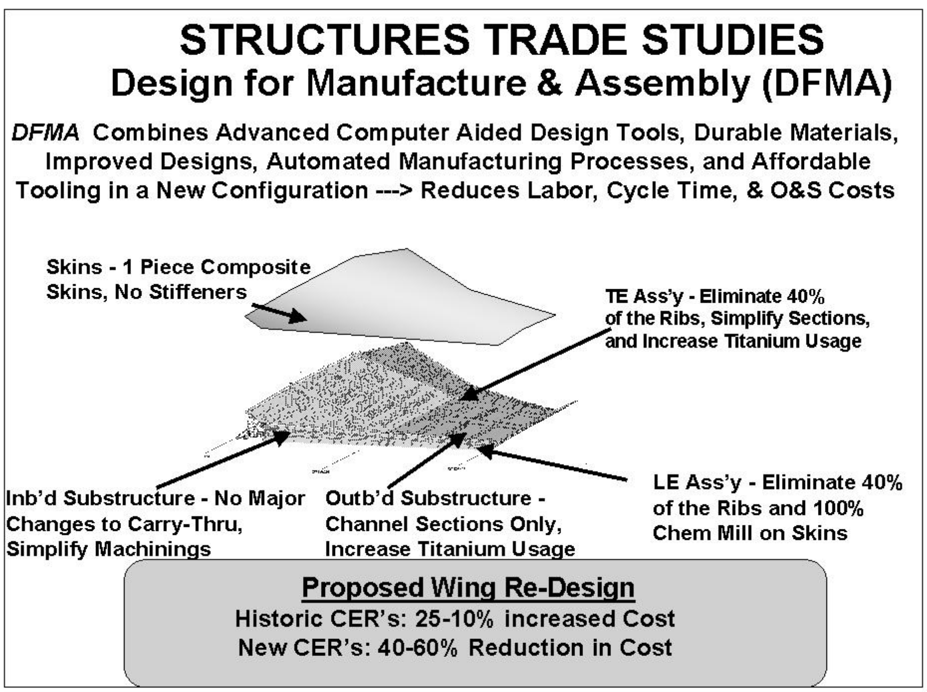

Figure 9

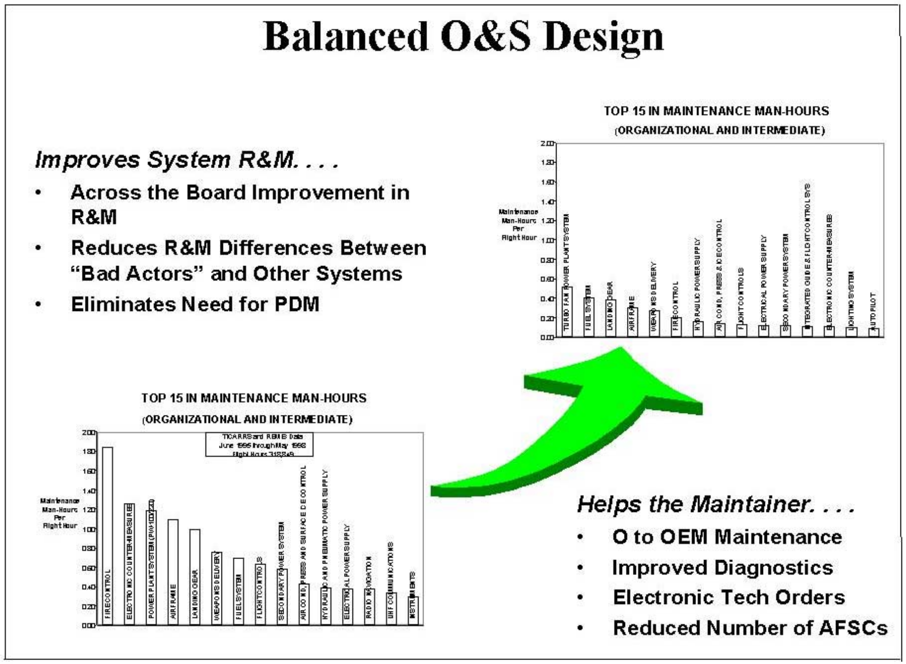

Figure 10

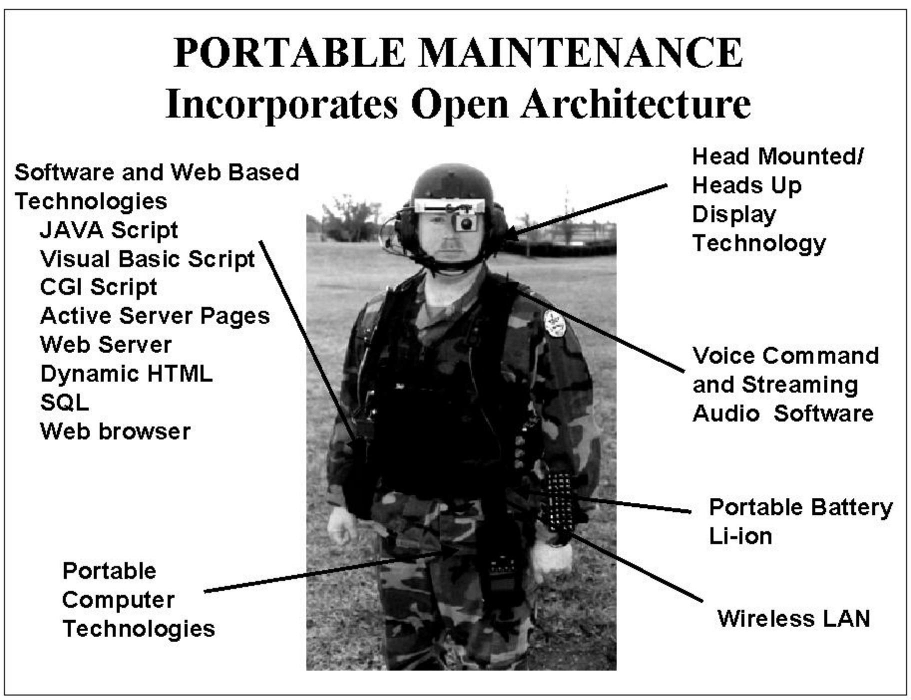

Figure 11

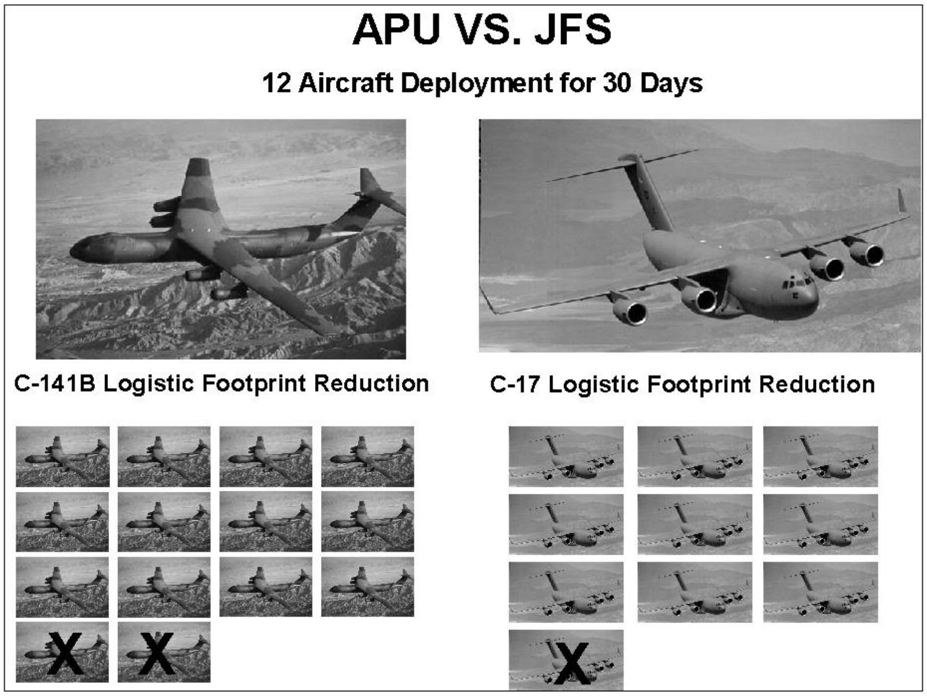
APU VS. JFS
12 Aircraft Deployment for 30 Days
C-141B Logistic Footprint Reduction
C-17 Logistic Footprint Reduction
X
X
X

Figure 12

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Future Initiatives for Obsolescence Mitigation Strategies

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Abstract The accelerating pace of technology change requires new approaches to the design, manufacture and through life support of military and long life cycle commercial platforms to minimise the effects of short-term technology obsolescence. The purpose of this paper is to describe medium and long-term strategies for the mitigation of obsolescence currently being considered in the UK. All complex military equipments are at risk from the effects of unmanaged technology obsolescence before and after they enter service. A systems engineering approach is described for the evolution of strategies that would involve co-operation between users and manufacturers to produce affordable through life solutions

Introduction Technology obsolescence in military and commercial long life cycle systems is now occurring at a far faster rate that at any other time in contemporary history. The gradual demise of military qualified parts and the availability of state of the practice Commercial off the Shelf (COTS) technology requires smart technology obsolescence management and technology insertion techniques to achieve and maintain military and commercial advantage.

The average rate of change of technology for semiconductor-based components available to meet future military requirements is expected to continue to decrease from its present three year term to less than two years by 2005. Components, which are presently being designed into new systems, have a high probability of being obsolete when the equipment enters service and unavailable when subsequently required.

Today the major thrust of electronics technology development is almost entirely dominated by high volume commercial requirements to satisfy the rapidly expanding market opportunities for video games, personal computers, mobile communications systems and new developments in the automotive industry. The computer and communications industry alone accounts for more than 70% of the market share. Although the military requirement for semiconductor products is now far greater than it has ever been, its actual share of the market has dropped from greater than 90% in the 1970’s to less than 0.5% today. The projected growth and viability of these markets is such that satisfying the military requirement takes a low priority with the major semiconductor manufacturers many of whom have now withdraw completely from this market sector.

The military is increasingly not the instigator of the design process for products that it requires in weapons platforms and has to react and respond to the imperatives that drive the process of change in the commercial market place.

The introduction of COTS components into military systems enables new technology to be incorporated quickly and at a fraction of the cost of traditional MOD funded research. These benefits are however accompanied by concerns of inadequate environmental robustness, the lack of traditional military screening processes and short-term commercial technology life cycles. Commercial product life cycles in turn create problems of accelerating functional and component obsolescence, resulting in the requirement to deliver frequent technology upgrades into systems that have not been designed

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to accommodate new technology insertion on a regular basis.

Whilst semiconductor technology obsolescence is a cause for long-term concern in the support of electronic components, other areas of technology obsolescence ranging from mechanical components to software are beginning to impact cost and operational through life support issues. Many of these technologies are inextricably linked within an equipment requiring a systems engineering approach to obsolescence management and not the conventional components based discrete technology solutions.

Research in DERA is showing that in future systems there is a growing interdependency between obsolescence solutions, reliability concerns and COTS insertion. Future obsolescence solutions have to ensure that all these areas of technology are addressed if the goal of effective low cost through life support is to be met.

The Present Management of Obsolescence: Within many organisations obsolescence management, if it is done at all, is done reactively. It is very rarely part of the design, development and sustainment policy and certainly the costs of reactive obsolescence management are generally unknown.

Within the military and most defence contractors obsolescence problems are generally solved serially within projects, on an ad hoc basis, with no lessons learnt feedback to other parts of the system or across the organisation. This situation arises as a direct result of the reactive nature of obsolescence management with the problems mainly being discovered during repair in response to equipment failure. At the time the parts status is discovered it may be to late for last time buys and the part is no longer available. Considerable cost may then be involved in finding an equivalent part or in the worst case having to redesign the system. The fact that an equivalent part can be found may only provide a short-term solution since the total parts obsolescence status of other components on the board or other boards within the equipment is not known.

The DERA approach takes a proactive systems engineering view of obsolescence management encouraging a “no suprises” culture that provides time to devise affordable solutions which can then be implemented across multiple platforms.

Obsolescence Management Tools: The DERA obsolescence management tools allow the customer to minimise future obsolescence at the equipment development phase, determine the obsolescence status before procurement, plan the most cost effective timescales for in service technology updates and manage obsolescence in legacy equipments to extend their service life.

The tools consist of a relational database, EPIC 2000, and ITOM an equipment configuration tool that allows the total parts distribution to be viewed at any level of indenture in a system.

The Electronics Parts Information Centre (EPIC 2000) contains information on over 1.2 million semiconductor devices consisting of:

- Original Component Manufacturer
- Full Parametric Information
- Availability Information
- International Parts Reference Numbers
- Possible Equivalents

The Integrated Technology Obsolescence Manager (ITOM) is a configuration management tool that can identify all the hierarchical levels in a military platform and populate them with data imported from the EPIC 2000 database. The functionality of ITOM is such that it is possible to obtain obsolescence information at discrete device, board, assembly, cabinet, LRU, system or platform level. It also has the ability to address any combination of multiple platforms and build standards.

The operation of the ITOM tool is via user friendly screens that follow logical paths to determine the current and projected availability of components at any level of indenture in a system or system of systems.

An availability code on each component indicates the timescales to obsolescence up to a maximum predicted value of 8 years. The predicted obsolescence timescales are derived from life cycle algorithms, which are continuously reviewed against expert opinion and knowledge of technology trends.

Methodologies The EPIC2000 database can be used as a stand alone tool that can be addressed by the user with single or multiple enquiries. This approach is however not recommended since it does not provide an overall view of the total obsolescence problem and can lead to increased cost of ownership with time.

For Military and Defence Contractor requirements, obsolescence is generally addressed on a project by project basis. Using the ITOM tool the system configuration is populated from customer furnished parts lists and then managed, on behalf of the customer through out the equipment life cycle. The customer is provided with regular obsolescence health check reports and priority alerts to inform of unexpected component non-availability. At any time the customer can receive suggested equivalents or alternatives to obsolescent parts to enable decisions on the most cost effective solutions to be reached.

The Evolution of Obsolescence Management:
At present in most legacy systems military grade qualified parts are still the norm. Obsolescence is managed via a combination of available military equivalents or best case commercial parts. Many of these systems however still have predicted future in-service lives in excess of 30 years or more with the result that the management of obsolescence at component level will become increasingly more difficult as the original military and equivalent commercial discrete devices become obsolete.

The accelerating rate of commercial technology and the proliferation of short lifetime COTS components in military systems will inevitably have an effect on the way technology obsolescence management evolves. Conventional component level obsolescence management tools will themselves become obsolete as new innovative semiconductor packaging and board level technologies move the lowest levels of system integration from discrete components to integrated board level assemblies.

Before this point is reached it is possible that functional obsolescence will demand a technology insertion which will increasingly be at board or subsystem level. It is most likely that the board level insertion will be a COTS component or a custom design containing COTS components.

The evolution of high density packaging techniques [1] for IC products is mirrored by new developments in board level technology that can take maximum advantage of Direct Chip Attach (DCA), Flip-Chip, Multi Chip Modules (MCM), Chip Scale Packaging (CSP) and Systems on a Chip technologies. These technologies are not designed to be repaired and attempts to do so will have unpredictable effects on reliability. The market for these new technologies is increasing very rapidly and future predictions show that as soon as 2002 they may account for about 8% of the total worldwide IC market.

It would seem probable therefore that obsolescence management will have to be delivered in a number of parallel ways in time scales determined by the availability of discrete device technology and the introduction of new integrated board level components. Conventional component level obsolescence management will have a window of opportunity after which the emphasis will change from delivering parts availability information, providing solutions bases on equivalent or alternative components, to that of advising on the time scales for the most cost effective new technology insertion at board level.

The period of twenty years or more that characterises the evolving obsolescence management strategies will be one were Military/Industry partnerships are vital and lessons learnt are widely disseminated across the stakeholder base.

National Obsolescence Centre Concept:
The concept is based on combining the resources of DERA and Industry to address present and future obsolescence management on a national scale and leverage this holistic advantage to provide a fast comprehensive low cost service to all the stakeholders.

The goal of the National Obsolescence Centre is to globally manage tri-service obsolescence problems in new and legacy equipments and play an active role in devising future obsolescence mitigation strategies jointly with MOD, DERA and Industry.

At present obsolescence is managed with a scattergun approach throughout MOD and industry. The cost penalties of this uncoordinated approach could eventually impact the defence budget to the detriment of R&D and new systems

procurement. The formation of a focussed national obsolescence centre would enable a system engineering approach to be adopted for the global management of obsolescence over the total MOD inventory. The single focus for all obsolescence information holds the promise of rapid response, economies of scale, and the elimination of duplication across the supplier and customer base.

The eventual requirement for the Centre would be to maintain a range of component databases, with current availability databases that would include:

- Semiconductors
- Passive components
- Connectors
- Cables
- Electrical components
- Relays
- Batteries
- Electro-optical components
- Microwave components
- Mechanical components
- Software
- Lessons Learnt

The lessons learnt database is a generic concept for describing the repository of solutions for obsolescence problems. For most of the component databases solutions such as equivalents, are an integral part of the individual technology database structure.

A physical lessons learnt database would contain information on custom solutions to electronic and mechanical problems including the future provisioning of sole sourced devices such as ASICS. It will address many of the "learnt from experience solutions" to COTS procurement and insertion problems throughout the equipment life cycle.

For most major defence contractors a large proportion of their output is dependant on the added value provided by Small to Medium size Enterprises (SMEs) who are finding it increasingly difficult to carry the financial burden of obsolescence management. Whilst the initial thrust of the National Obsolescence Centre will therefore be to provide an affordable obsolescence management service to small and medium size companies it the capability to service any level of stakeholder involvement.

Total Inventory Obsolescence Management:
If the total hierarchical structure and component population of all MOD equipments were lodged at the Centre a health check of all equipments could be performed on a regular basis and the customer informed of component alerts and the timescales in which they need to be addressed. In this way the total costs of managing obsolescence across MOD would be dramatically reduced since there would be no suprises and adequate time would be provided to determine the optimal remedial actions.
The same service could be provided for long life cycle commercial platforms in the aerospace, oil and medical industries where economies of scale could significantly reduce through life costs.

The alternative is to continue the present trend and create a series of unique solutions to a single problem across the total customer base with increasingly large cost and deployment penalties to the customer.

Built for Life Electronics
A Research project has started in FY 99/00 that will specifically address the development of Built for Life Electronics based on the principles of Physics of Failure [2]. Physics of Failure technique have shown that failure mechanisms are far from random and it is becoming possible to predict failure times of electronic assemblies with a degree of accuracy that promises the capability of invoking the concept of a guaranteed life. The technologies for guaranteed life or maintenance/failure free operating periods (M/F-FOP's) are currently being funded by MOD, DERA and many of the major defence contractors in the US and Europe through the CALCE initiative at the University of Maryland. The DERA programme will investigate the applicability and impact of these techniques at system level and the possible future direction of this type of research within DERA and industry.

Physics of Failure (PoF): Physics of Failure is an approach to develop reliable products that uses the knowledge of root cause failure mechanisms to prevent product failures in the field by incorporating PoF at the product design stage.

The PoF approach incorporates reliability into the design process by establishing a scientific basis for evaluating new materials, structures and electronics technologies. An important aspect of the technique is the ability to predict the time to

failure of specific failure mechanisms throughout the system geometry.

The Physics of Failure approach involves:

- Identifying potential failure mechanisms including, chemical, electrical, physical, mechanical, structural or thermal
- Identifying failure sites including component interconnects, board metallisation, or external connections
- Failure Modes including electrical shorts, opens or problems associated with failure mechanisms resulting in electrical deviations beyond specification.
- Identifying failure mechanism models and their input parameters including materials characteristic, relevant geometry at failure sites, manufacturing defects and environmental and operating loads.
- The provision of information to determine electrical, thermal and mechanical stress margins.

Physics of failure models can be applied to accelerated life testing of electronic components to assess the reliability and lifetimes under normal stress conditions. As the use of the PoF approach increases this method may become a routine process during the design and evaluation phase of the product lifecycle

M/F-FOPS: Physics of Failure techniques can be used to design a system for maintenance and failure free operating periods. Maintenance free operating period (M-FOP) is defined as a period of time during which a system is operational and is able to carry out its required functions without maintenance and without encountering failures. A failure free operating period (F-FOP) is defined as a period during which no failures resulting in a loss of system functionality occur

The M/F-FOPs approach is the basis of the concept of built for life electronics when used in a defined operational envelope.

When built for life electronics is used to describe a disposable or throw away item it could be described as an F-FOP. A system containing multiple built for life units could be an M-FOP which contains units with known remaining life and hence known maintenance schedules.

Health Unit Monitors: Health unit monitors (HUMs) are required to monitor built for life equipments to ensure that excursions outside the agreed operational envelope are observed. New DERA initiated research in the CALCE programme is designed to enable the HUMs to perform the dual function of Event Monitoring and Life-Consumption monitoring by mapping event data into damage accumulation models to provide indications of remaining life.

Open Systems [3]: To obtain the maximum cost and operational advantage from built for life units they should be compatible with an open systems approach to equipment design.

An open system is a system that implements sufficient open specifications for interfaces, services and supporting formats to enable properly engineered components to be utilised across a wide range of systems with minimum change. The success of open systems, in future military systems, lies in the choice of commercially supported specifications and standards for interfaces. Interface standards generally have long lifetimes, some as long as 25 years, and can outlast any particular product, vendor or technology.

The attraction of open systems is due to:

- Portability-The ease with which a system, component, data or software can be transferred from one hardware or software environment to another.

- Interoperability-The ability of two or more systems or components to exchange and use data

- Scalability-The capability of hardware and software to accommodate changing workloads

- Vendor independence-Products available on a commercial basis from multiple vendors

- Supportability- easy upgrades or technology insertion

An open systems approach to future designs promises to solve many of today’s problems and specifically to allow maximum advantage to be taken of the availability of state of the art COTS

technologies in an incremental acquisition process.

DoD as far back as 1994[4] recognised the problem and issued a directive that instructs programme managers to employ open systems as a design consideration in defence systems engineering.

Open systems provide an opportunity to achieve lower cost affordable designs which can readily accommodate new technology insertion over the whole life of the system with the additional advantage that upgrade technologies can be state of the practice technology from multiple suppliers. The approach also mitigates against the risks of obsolescence by using commercially supported interface standards permitting upgrades and new technology insertion at relatively low cost.

A Possible Future: The prospect of maintenance and failure free operating periods for electronic components in open architecture systems promises to provide a neat low cost solution to the obsolescence problem as well as addressing the short term technology upgrade problems in military and commercial equipments.

The incorporation of low cost life consumption monitors based on highly integrated environmental sensors holds out the promise of predicting in real time the remaining life of electronic assemblies.

The advantages of no obsolescence problems, known reliability and seamless technology upgrades coupled with a faster development timescale, a better product at lower cost with a fast time to market will satisfy the requirements of both military and commercial customers.

Conclusions: Proactive obsolescence management will require a culture change in both Military and Defence Contractors. It is not difficult to see that if obsolescence was managed on a tri-service basis considerable insight into major problem areas and valuable lessons learnt could be fed back into research, development and procurement cycles.

Obsolescence could be managed to greater advantage if the Military and Defence Contractors teamed jointly to form a National Obsolescence Centre that could address obsolescence on a global basis across the total customer inventory. The concept of teaming offers many areas for cost reduction within MOD and Defence Contractors whilst adding to the overall knowledge of the participants. It would have the added advantage that work was not duplicated and solutions could be disseminated to all the participants across multiple platforms in real time. Defence Contractors who also address the commercial market could gain possible commercial advantage by predicting reduced levels of through life maintainability.

It is now possible, albeit with some difficulty, to manage semiconductor component obsolescence, that is to maintain the equipment to its originally specified functionality throughout its service life. In most cases however this may not be sufficient since the rapid acceleration in technology innovation will make the original equipment itself functionality obsolescent. A systems engineering approach to obsolescence management is required to determine the most effective solutions for equipment modifications, upgrades or new technology insertion at any point in the equipment life cycle.

The increasing use of commercial off the shelf (COTS) components in military and long life cycle commercial equipments will exacerbate the problems of component obsolescence management. COTS components undoubtedly save front end costs through the development and procurement stages when compared to traditional military components. They also carry the risks of technology development being driven by commercial requirements rather than to provide enhanced capability in a military scenario

The solutions to component obsolescence, commercial technology insertion and reliability are increasingly inter related as new technology evolves. Cost effective solutions, based on open systems design, with the availability of guaranteed life COTS components, must address these areas simultaneously over a wide range of technologies to achieve the optimum performance/cost benefits.

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Open Systems Approach
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EPIC 2000

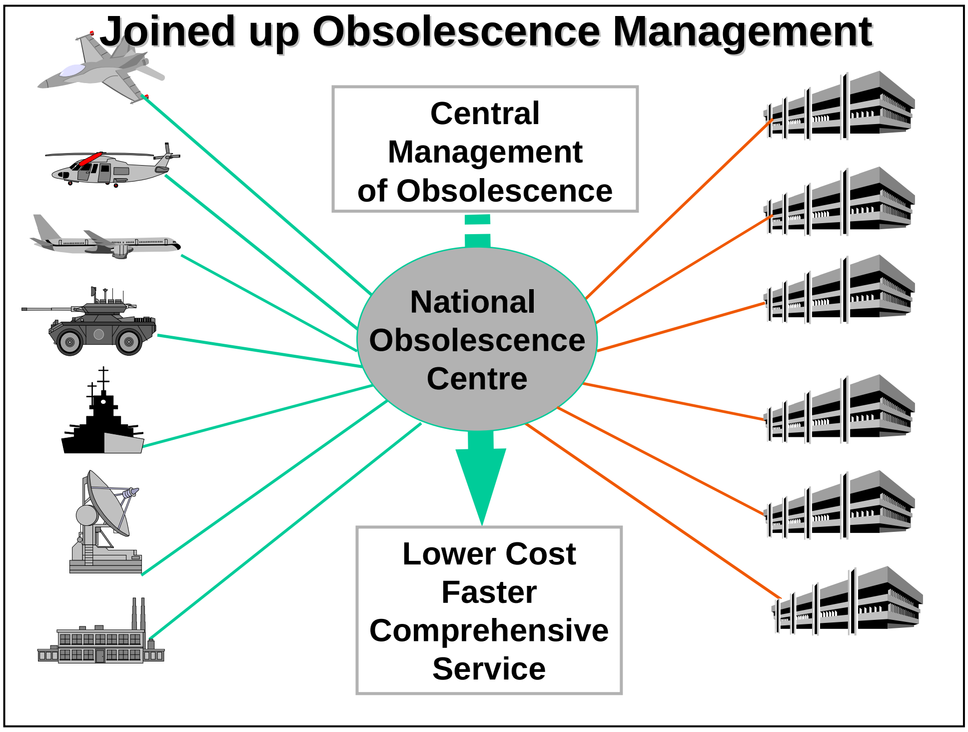
- Relational Database
- Data Currency
- Parts Description
- Parts Equivalence
- Obsolescence Predictions

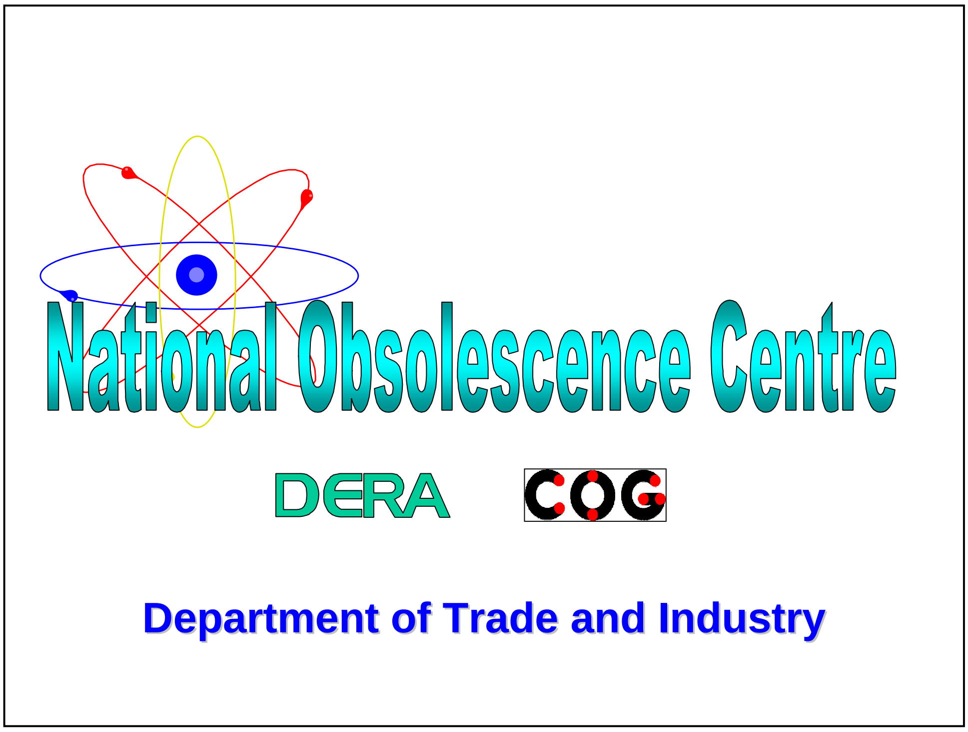
What we require is to

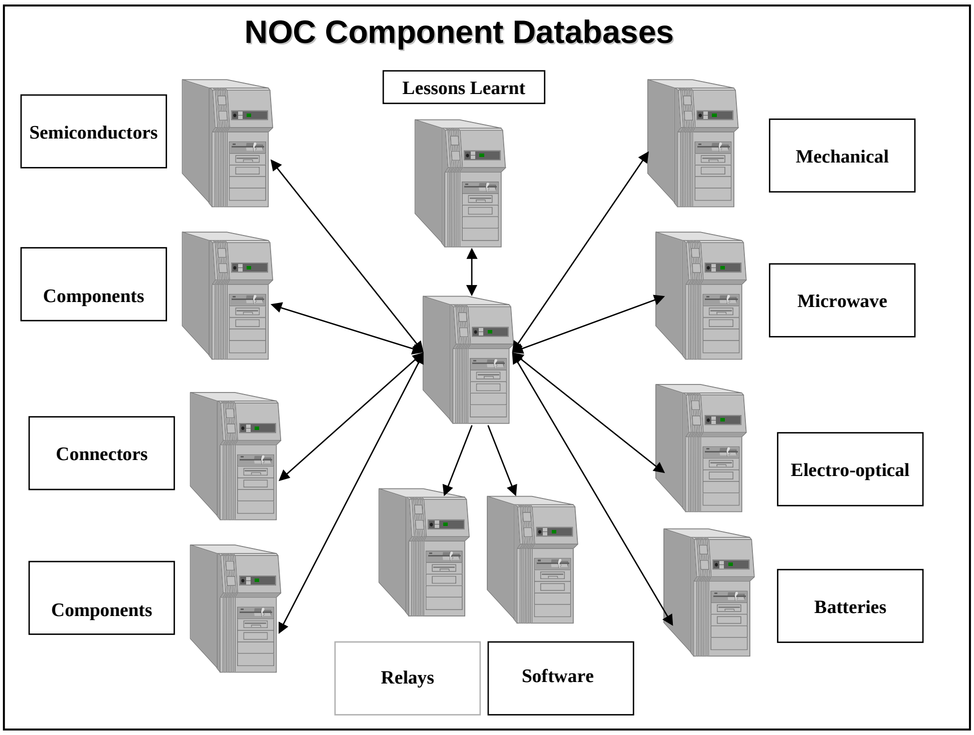
✢ **Turn <u>Reactive</u> Obsolescence Management**

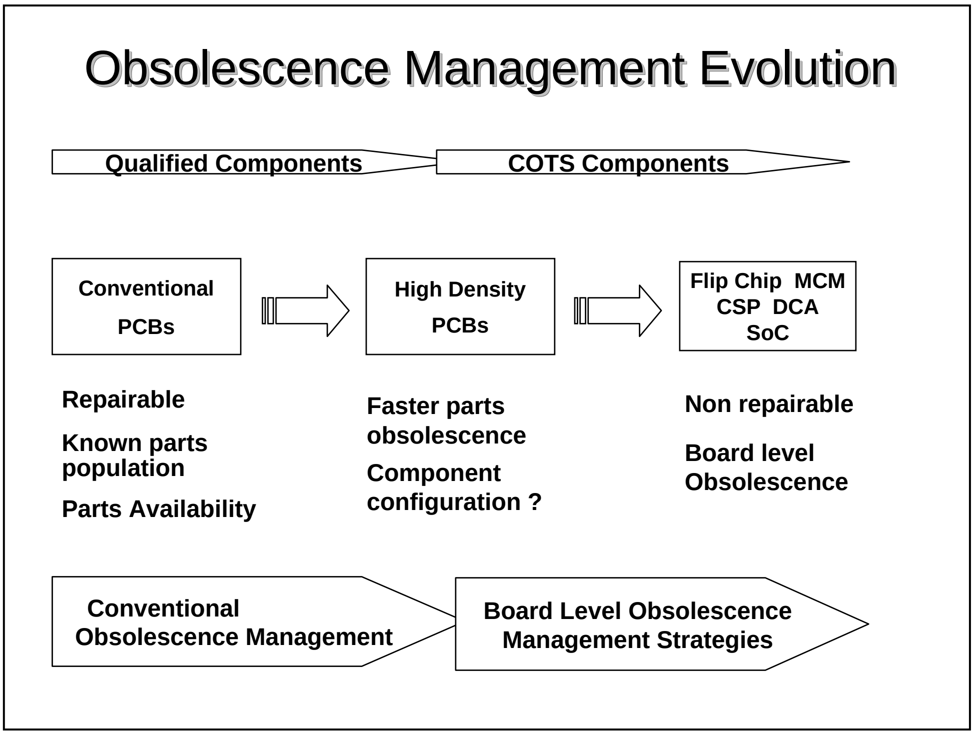
✢ **into <u>Proactive</u> Obsolescence Management**

- Continuous real time health checks of the total component count across multiple platforms from multiple users
- Simultaneously inform every user who has a problem the location and extent of the problem
- Solve the problem once only and inform all the owners


Joined up Obsolescence Management
Central Management of Obsolescence
National Obsolescence Centre
Lower Cost
Faster
Comprehensive
Service


National Obsolescence Centre
DERA
COG
Department of Trade and Industry


NOC Component Databases
Lessons Learnt
Semiconductors
Mechanical
Components
Microwave
Connectors
Electro-optical
Components
Batteries
Relays
Software


Obsolescence Management Evolution
Qualified Components
COTS Components
Conventional PCBs
High Density PCBs
Flip Chip MCM CSP DCA SoC
Repairable
Known parts population
Parts Availability
Faster parts obsolescence
Component configuration ?
Non repairable
Board level Obsolescence
Conventional Obsolescence Management
Board Level Obsolescence Management Strategies

Physics of Failure

A Probabilistic Science Based Approach
to Reliability Prediction

- Identification of Failure Modes, Mechanisms and Failure Sites prior to Build
- Reliability Predictions at Design Stage
- Virtual Reliability and Qualification
- Software and data for Circuit Board and Device Level Analysis

Maintenance/Failure Free Operating Periods M/F-FOPs

Maintenance Free Operating Periods M-FOPs

A period of time during which a system is able
to carry out its required function
without maintenance activity
and without encountering failures

Failure Free Operating Periods F-FOPS

A period of time during which no failures
resulting in a loss of systems functionality can occur

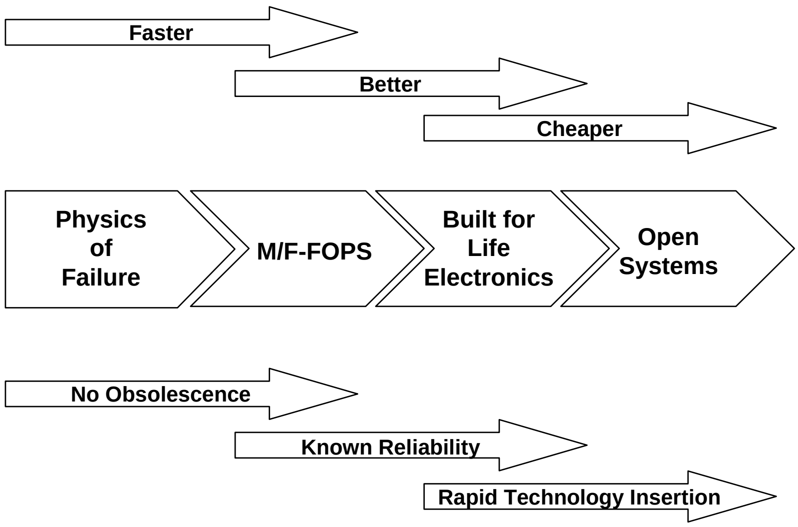
Open Systems

An Open System is a system that implements sufficient open specifications for interfaces, services and supporting formats to enable properly engineered components to be utilised across a wide range of systems with minimal change

Characterised by

Commercially supported specifications and standards for system interfaces

Future System Concept



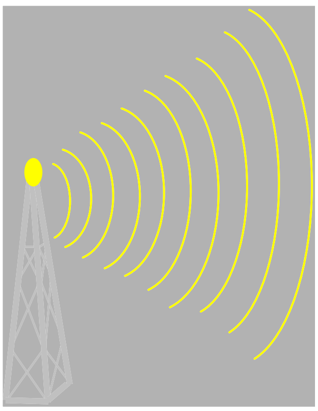
Built for Life Electronics

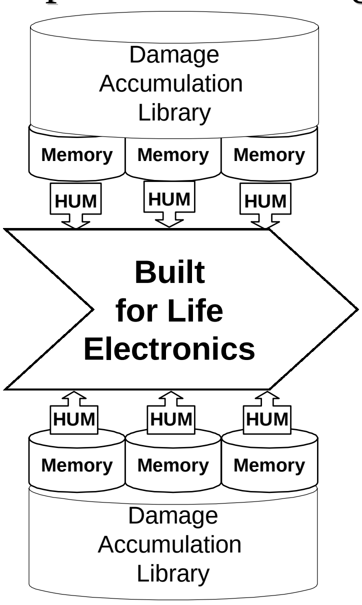
What does the user want to know

Remaining useful life

Difference between manufacturers guaranteed life and that lost due to wear out and out of specification excursions

Built for Life Electronics
Life Consumption Monitoring





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Leveraging New Information Technologies to Manage Obsolescence

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In the new economy of digital technology the transition rate of component level functionality is transitioning at an accelerated rate introducing greater functional complexity. As voltage out put scales downward and micron line width design rules are reduced there are new generations of digital technology that offer superior functionality that is more reliable, uses less power, less real state, less weight and smaller power supplies. The newer generations of component technology are rapidly causing the older generations of component technology to become obsolete because the cost of various functionality commodity groups are reduced with the scaled down designs. At i2 through our global semiconductor library maintenance we are recording 37,000 component discontinuance notifications on an annual basis. Within the digital category a new generation of microprocessors is being introduced every 18 months and a new generation of memory type devices is being introduced every 9 months with speed and density increases. This high rate of technology transition is impacting the production and spares support to sustain weapon systems that require ten, twenty, thirty or more years of operational support.

- To manage component obsolescence new information technologies are providing specialized software tools and content libraries that can be used to reduce the financial impact of semiconductor obsolescence. An example of advanced obsolescence information tooling that is on the market is offered by i2 Technologies. Built into their obsolescence management software product called TACTRAC the software provides life-cycle projections that can be used for component selection or assessment of existing designs. The i2 component life cycles can be used to provide a continuous analysis of a weapon systems production readiness. The same component life cycle information can be used during the component selection phase to screen out obsolescence at the component level and insure state-of-the-art components are be selected for a new design or modernization. If software is the motor the fuel for the software is daily updates on changing component availability. This type of information is supplied by the i2 global content libraries that contain all semiconductors made anywhere in the world. As component availability changes, new source, introductions, discontinuances, life of buy notifications, quality changes, packaging changes and functionality changes the delta of change is sent to i2’s customers in real time and the software tell the customer where the parts are used in their product configurations. In addition to the changing component “availability notification” the content libraries also supply all form, fit and function equivalent parts thus providing the user with all replacement options if they exist. The TACTRAC capability offered by i2 also provides a means of “secured” data exchange allowing a collaborative operational environment to solve common obsolescence problems at the component level. This allows different divisions or program offices to share visibility on common component obsolescence problems. Teaming a common problem when evaluating solution options or leveraging the

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collective purchasing power on a common problem can save thousands of dollars to a specific program. Fragmenting the workload or leveraging the purchasing power to make a bridge achieves such savings or lifetime buy. Teaming common problems will also reduce the time to resolve the common problem. Clients using i2's TACTRAC obsolescence service have been able to reduce the cost impact of obsolescence by 15 to 20%. Such savings is obtained by leveraging collaborative operational environments on common problems, use of life cycle projections and daily notifications of changing component availability. By implementing this type of tooling and having access to the content libraries this allows a customer to optimize in cost savings the following work process flow:

- Reduce time to market for new designs or modernizations
- Component selection to minimize single source situations
- Consolidate technology baseline within an enterprise or program
- Reduction of imbedded obsolescence using life cycle projections
- Timely technology insertion and planning for modernization priorities
- Collaboration on common component obsolescence problems

Studies by the US Department of Defense have shown that 70% of weapon system expenditures to support a weapon system are made in the after market years. Proper implementation of modern information services by equipment contractors and military program offices could reduce weapon system "cost of ownership" by 15 to 20%. Reacting to individual component obsolescence problems on a situational basis can become cost prohibitive. Especially to programs that are aged or are past their mature funding years. To properly utilize the newer information technologies will require a cultural change within the suppliers that build weapon systems. In the new economy common problems can be teamed protecting the security of each company that is participating in the "teaming" effort.

A Quasi-Copysafe Security of Documents on Normal Papersheets

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Abstract

A combination of 2D barcode with digital signature and normal text with polygonal watermark is proposed. Against synchronisation attacks the watermark reference points are also included in the 2D barcode and secured by a digital signature, whilst the 2D barcode block(s) are embedded in the text.

Keywords : 2D barcodes, robust digital watermarks, digital signature, copy-management, access control

1. Security of documents

Security of documents is a general user requirement. During their lifecycle documents nowadays are born as electronic digital originals and printed only later. Copies of documents are transformations converting the same content either onto digital or analogue form. One factor of the security is the confidentiality of the document content. In this paper the confidentiality of a document content printed onto normal papersheet pages is in the focus. Let's assume that such a confidential system is going to be developed.

A basic system funtion : **Confidentiality**

Basic assumptions :

It is a general human habit, and so an implicit user requirement, that every important document is going to be printed.

Executives dislike watching a monitor screen, when reading over lengthy materials.

Our hypothesis is that this is thrue for confidential/secret materials as well, so it is a requirement to protect confidentiality/secrecy of printed documents by means of copy management and logical access control methods.

System functions :

Copy management
Logical access control

Techniques applicable :

Encryption systems
Steganography/digital watermarking
Access control systems

Access control : An access control system resist unauthorized access to the data

Encryption : Encryption resist unauthorized access to the content of a document.

Paper presented at the RTO SCI Symposium on "Strategies to Mitigate Obsolescence in Defense Systems Using Commercial Components", held in Budapest, Hungary, 23-25 October 2000, and published in RTO MP-072.

Steganography : Hiding/embedding the secret information beyond a cover text – that is steganograpy. But unlike encryption, steganograpy in itself does not resist access to the data and it is effective until the detecting of the hidden communication.

Problems : Used in point-to-point communication the information channel can be subject of various hostile attacks (jitter attack, etc.) aiming to fool the receiver/detector by either impairing or diminishing or removing the secret message.
After a successful hostile attack the hidden message cannot be recovered. As to paper media attacks these are usually detection-disabling or desynchronization geometric data manipulations.

2. Technical steganography approaches

Various techniques of technical steganography can be applied as well :
Even if the document content is encrypted, spread spectrum modulation, scattering make difficult to detect or jam transmission. Camouflage, special inks, materials, masking algorithms are widely in use as follows :

Blind colour approach

A blind colour is „invisible” for a copier/scanner/video/camera/etc. equipment.
Assumptions : An original document is printed by means of a colour printer, and
the really confidential/secret paragraphs, details, or data of the document are to be printed by a blind colour (red, orange, etc.), and
the rest of the confidential/secret document is to be printed by a non-blind colour.
Under the above assumptions the confidentiality of a photocopied/scanned/photod document – although copied – will be not corrupted indeed, because the confidential details are not on the copy.

Problems : Although a certain colour can be blind only for a subset of photocopier/scanner models, but not for all models.
Even with carefully selected photocopier models in office, original pages of confidential content can be fetched and photocopied/scanned outside by other models.
Video/photocamera, etc. can also smuggled in for copying the whole material.

Special copysafe papers are expensive and although having been copied on one model onto a copysafe special page the copy of the text is really unreadable, but having been copied on other colour copier models, the output can be a perfectly readable text.

Chemical reaction (heat or light effects) in the copier

Assumptions : The really confidential/secret paragraphs, details, or data of the document are to be printed by a special ink, and
in the printer there is no heat-effect when printing the original page, and
the background colour of the text is painted by a special ink (or the text on the page is printed by a special ink), wich will become of the same colour of the background, and
in the copier there is a heat-effect over a threshold temperature (or light effect), and
when making copies, only that copier is in use (heat-effect cannot be avoided.
Under the above assumptions the confidentiality of a photocopied/scanned/photod document – although copied – will be not corrupted indeed, because the confidential details are not on the copy.

Problems : There are too many underlying assumptions. In practice these prerequisits are difficult and in large organisations rather expensive to meet.

Conclusion : If we want to avoid risky as well as expensive proposals, we had better to find a commercial solution, perhaps a combination of normal paper and commercial ink and diverse printing equipment already existing in the environment. An integration of some carefully selected off-from the self commercial technologies will do a lot of good to the system.

3. Digital watermarking approaches

System subfunction : **Fingerprinting**

Copies of digital documents are indistinguishable from the original. Fingerprinting (hidden serial numbering) makes them distinguishable, which may become important in case of tracing for attackers. A hidden unique marking of each copy of a document makes distinguishable the original from the copies, and each copy from the other one. Hiding the secret information involves on the one hand hiding the location (or the reference) of the embedded information and on the other hand spreading the hidden information.

Digital watermarking techniques

On the expense of less embedded information into the cover text and using smarter methods, even if the communication has already been detected and the algorithmic principle of the embedding became public, a digital watermark can permanently reside in the host data, able to resist against hostile attacks, but unlike encryption, fragile watermarking in itself does not resist access to the data.

Robust digital watermarks are difficult to remove, impair from the cover text, but
fragile watermarks are relatively easy to remove, impair, destroy from the cover text.

Invisible watermarks

At least three invisible marking techniques are applicable for formatted black and white text printing:
By slightly changing

- interline spacing (Line-shift coding),
- intercharacter spacing (Word-shift coding),
- character font features (Character coding) a publisher can identify each document copy.

Because of underlying assumptions, line-shift decoding does not require the original unmarked copy. Although the marks robust enough to survive consecutive (ten generations) photocopying (see Ref. 1), theoretically removable, corruptable. The marks are fragile digital watermarks.
Problems : Any black and white marks in a formatted black and white textpage, layed out by any technique can always be removed by simply retyping, or by means of high resolution scanners and optical character recognition (OCR/ICR) and reprinting the text using a new character font and layout format.

Visible watermarks

In offices there has always been a requirement to register copies of documents. 1D barcode or serial numbers identified each copy (and pages of the respective copy) on the margin. By means of security printing scrambled barcode can be made in printing houses.

When watermarks generated, they should be innumerable (distinguishable from each other). Because of tracing back pirated copies, in fingerprinting applications it is important to identify the recipient of each individual distributed copy in the watermarks respectively. The identifier of the sender, the event (when and where) identifying attributes, and a document specific message digest are useful as well. In order to aviod taking a valid mark from one copy and pasting it onto another one, the sender signs the mark with a cryptographic key. Digital signature ensures, that the electronic document has not been altered.

In order to ensure security against hostile attacks (data manipulation), erasure of the watermark, or unauthorized access of the watermark content, cryptographic keys are very useful.
- Steganograpy in combination with a symmetric(secret) key – that is secret key watermarking.
- Steganograpy in combination with an asymmetric(public) key – that is public key watermarking.

Public key watermarking

A watermark is only robust as long as it is cannot be read by everyone. Public watermarks (where the key is public), are vulnerable to attacks unless each receiver uses a different key (but this is difficult in practice). Scrambled images can be descrambled by means of an optical grid or lens. A multilevel authentication system was proposed (see Ref . 2),where scrambled images can be verified by

variable (electooptical) filters, unique optical decoders. Another option is a special scrambling hardware in the camera.

Assumptions when copying a scrambled image, if the image is coloured (but not the text), and
during printing a proper data resolution/frequency (1200 bpi) used,
and a commercially available colour photocopier is applied,
than the embedded mark cannot be copied.

Problems : But grayscale, or black and white scrambled images are copiable.
High resolution /non-commercial colour scanners can make perfect copies of the embedded images as well.
The reason why scrambled indicia is still used in offset or intaglio security printing (banknotes) and recently in personalisation of personal ID, is that the scrambling algorithm is secret (the key is in the hardware in the camera).

Secret key watermarking

Spread-spectrum radio communication is a symmetric key cryptosystem. The band spread is accomplished by a secret key(a signal, which is independent of the data) and a synchronized by the key reception at the receiver is used for despreading.

An example (see Ref. 3) to that, when parameters of a control signal (sequential impulse groups characteristics) are exploited to represent autonomous control information of remote control for vehicles or flying objects. That special data communication technique was proposed for transmission of some autonomous control attributes in a common one way channel parallel at the same time (Patent No.206418). The method in itself is independent of the field of application, circuit solution, or communication media. The communication channel can either be a cable, or a radiochannel (with different modulation options), either ultrasonic, or infrared, etc.

The modulating signal - an impulse group - can be seen in Fig. 1. One of the autonomous attributes is represented by the impulse-number in an impulse group (7). Another information is represented by the time interval between two starting pulses of two consecutive pulse groups (8). The third information is represented by the time interval rate of the existance (5) and nonexistance (6) of a certain pulse.

It is almost impossible to remove or replace a watermark, when that requires the secret key.

Problems : Attackers rather try to modify the watermark content. Or try to discredit the authority of the watermark by some ambiguity (inversion or interpretation) attack. By means of reverse engineering many watermarking schemes might be approximated.

Fake original documents, fake watermark data can be made. If different watermarks are embedded in the same host data it ought to be still possible to identify the first(authoritative or copyright) watermark.

Possible solutions : But also some methods are devised to construct noninvertible watermarks so that making them signal-dependent.
Information-losing marking schemes are also non-invertible, since inverses cannot be approximated closely enough.

A combination of watermarking and timestamping (provided by a trusted third party), or notarization, or a combination of watermarking, timestamping, cryptography, access control, 2D barcode.

4. Conditional logical access control

2D barcode approach

Assumptions : 2D barcode reader and printer,
and an organisationwide logical access control system are available, and
the really secret paragraphs, details, or data of the document are to be printed by 2D barcode (see Fig. 2) or glyph, and
the document qualification is : secret, than a public key encryption is also used, and
ciphering and deciphering software/hardware is also available, and
the rest of the confidential/secret document is to be printed as a normal text, than
only the relatively short secret details (resolutions or important data in the protocol of an executives' meeting, etc.) ought to be watched by executives on a screen.

Under the above assumptions the secret content of a photocopied/scanned/photod document – although photocopied – will be not corrupted indeed, because though the confidential details are in the copy (and those remain copyable), but encryption (a digital signature or stamp) prevents the data content from unauthorized logical access. The latter has as good information protection performance as of a digital signature over a digital electronic document or file.

A combination of 2D barcode with digital signature (see Ref. 4) and normal text with polygonal watermark (see Ref. 5) is proposed. Against synchronisation attacks the watermark reference points are also included in the 2D barcode and secured by a digital signature, whilst the 2D barcode block(s) are embedded in the text.

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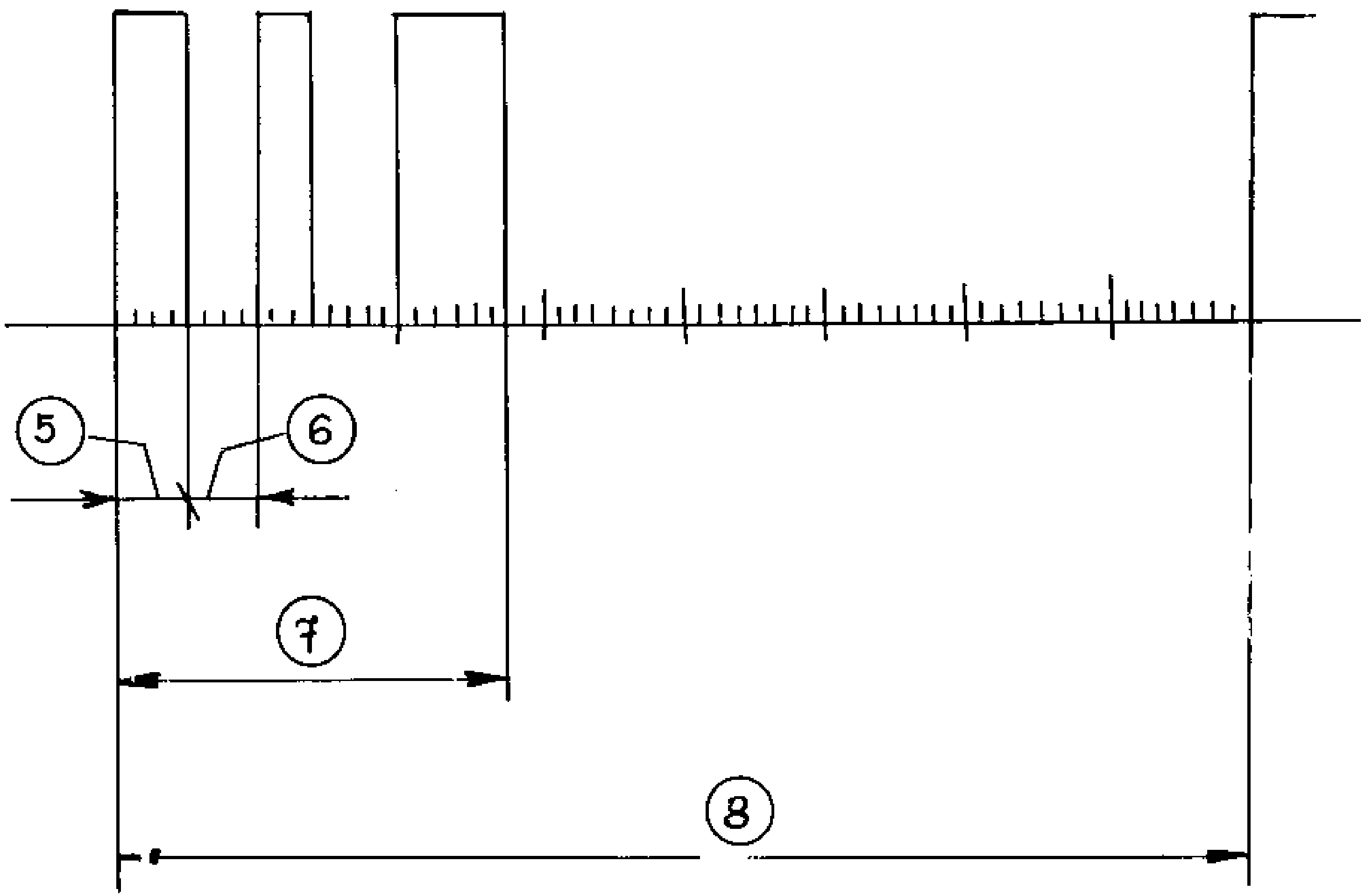
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